ADA 119129

TECHNICAL REPORT
NATICK/TR-82/016

Effects of Gender, Load, and Backpack on Easy Standing and Vertical Jump Performance Volume II

BY RICHARD C. NELSON
AND
PHILIP E. MARTIN

BIOMECHANICS LABORATORY
THE PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PENNSYLVANIA

MARCH 1982

UNITED STATES ARMY NATICK
RESEARCH & DEVELOPMENT LABORATORIES
NATICK, MASSACHUSETTS 01760

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NATICK TR-82/016	2. GOVT ACCESSION NO. AD-A119129	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) VOLUME II. EFFECTS OF GENDER, LOAD, AND BACKPACK ON EASY STANDING AND VERTICAL JUMP PERFORMANCE.		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period October 1, 1979 to August 31, 1981 6. PERFORMING ORG. REPORT NUMBER IPL-240
7. AUTHOR(s) Richard C. Nelson, Ph.D. Philip E. Martin, M.S.		8. CONTRACT OR GRANT NUMBER(s) DAAK60-79-C-0131
9. PERFORMING ORGANIZATION NAME AND ADDRESS Biomechanics Laboratory The Pennsylvania State University University Park, Pennsylvania 16802		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6.2, 1L162723AH98AJ005
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Research and Development Laboratories ATTN: DRDNA-ICCH Natick, Massachusetts 01760		12. REPORT DATE March 1982 13. NUMBER OF PAGES 74
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

loads	load carrying	military personnel
males	anthropometry	exercise
females	combative movement	field tests
frame-pack systems	performance	field operations

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to determine the effects of loada worn or carried and the type of backpack uaed on parameters of the easy standing and vertical jumping performance of men and women. Fourteen men and eleven women participated in the easy standing test and eleven men and ten women participated in the vertical jump under each of the following load conditions: Load 1 - baseline (shorts, t-ahirt, sneakers); Load 2 - fighting gear (utility shirt and trousers, boots, ALICE fighting gear); Load 3 - combat gear (Load 2 plus PASGT helmet, PASGT armor vest, aimulated M16 rifle); Load 4 - combat gear and 20-lb backpack

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load (Load 3 plus backpack with 20-lb load); Load 5 - combat gear and 35-lb backpack load (Load 4 plus an additional 15 lb in pack). The men were also tested under a sixth load condition: Load 6 - combat gear and 50-lb backpack load (Load 4 plus an additional 30 lb in pack). The subjects carried Loads 4 through 6 using four different backpack systems. Two of these conaisted of Army framea equipped with the standard Army pack. The third was an experimental item, a packboard made of rigid aluminum, used with the Army pack. The fourth backpack was a commercially-available, internal frame system. Analyaes of the easy standing data indicated that both men and women demonstrated greater stability with the medium than with the lighter or heavier loada. The internal frame backpack resulted in greater postural stability relative to the three, external-frame systems. Increasing loads produced a aystematic, linear decrease in vertical jumping performance. Analyses of the effects of backpacks on the parameters of jumping performance revealed few differences among the packa. However, it was found that height of jump was somewhat better with the internal frame system than with the external-frame backpacks. Additional analysea were carried out on the trial-to-trial reliability of easy standing and on ground reaction force parameters of vertical jumping adjusted for body weight and system weight.

PREFACE

This is the second of four volumea comprising the finsl report of research performed under Contract Number DAAK60-79-C-0131 with the Individual Protection Laborstory, US Army Natick Research and Development Lsborstoriea, Natick, Maasschusetta. The work waa formulsted snd directed by Drs. Carolyn K. Benael and Richard F. Johnson, Humsn Fsctora Group, Individual Protection Laborstory. Dr. Bensel was the contrsct monitor snd Dr. Johnson wss the slternste.

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INTRODUCTION

This is the second of four studies on the biomechanics of load carrying behavior being conducted in the Biomechanics Laboratory at The Pennsylvania State University under the direction and sponsorship of the Army Natick Laboratories. The first study in this series dealt with the effects of gender and load on combative movement performance.[1] The subjects performed under five (women) or six (men) load conditions which included only one frame-pack system, the ALICE LC-2. This second study was designed to further compare male and female performance, evaluate the effects of load, and also to compare four frame-pack systems.

Fundamental movements of easy standing and vertical jumping were selected for this purpose since both had been used successfully in previous load carrying experiments.[2,3] These tests used sophisticated laboratory force platform and on-line computer systems. The subjects, experimental design, test procedures, and results for these tests are described in separate sections later in this report.

The four frame-pack systems and six load conditions were common to both easy standing and jumping experiments. Consequently, descriptions of the backpacks and loads are presented in this section.

Backpack Systems

The four backpacks used in this study included three with external frames and one with an internal frame. The same top-loading pack, a standard Army item, was used on each of the external frames. A brief description of each system is included here. Appendix A contains additional information on these items.

a. ALICE LC-2 is the Army's standard frame. It is made of aluminum tubing and has foam-padded shoulder and lower back straps. The waist belt, made of wide nylon webbing, is attached to the padded back strap.

[1] Nelson, R.C. and P.E. Martin. Volume I. Effects of Gender and Load on Combative Movement Performance (Tech. Rep. NATICK/TR-82/011). Natick, Massachusetts: US Army Natick Research and Development Laboratories, February 1982.

[2] Nelson, R.C., T.E. Clarke, and R.N. Hinrichs. An Investigation into the Biomechanics of Load Carrying: The Effects of Gender, Body Size, and Backpack on Load Carrying Behavior. Natick, Massachusetts: US Army Natick Research and Development Laboratories, in preparation.

[3] Nelson, R.C., T.E. Clarke, and R.N. Hinrichs. An Investigation into the Biomechanics of Load Carrying: The Effects of Load and Backpack on Load Carrying Behavior. Natick, Massachusetts: US Army Natick Research and Development Laboratories, in preparation.

b. ALICE LC-1 was the standard Army frame prior to the introduction of the LC-2. The frame itself is of the same design as the LC-2. However, the shoulder and back straps are of different dimensions and are not foam-padded. In addition, the waist strap is made of narrow webbing and attaches to the frame.

c. LOCO is a commercially-available, internal-frame system. The frame consists of two, vertical, aluminum stays which extend the length of the pack and are on the side of the pack closest to the wearer's body. The pack itself is a top-loading bag to which foam-padded shoulder straps and a waist belt are attached.

d. PACKBOARD is an experimental item which was fabricated for this study. It consists of a flat sheet of aluminum. The shoulder, back, and waist straps attached to it are identical to those used with the ALICE LC-2.

These four backpack systems are pictured in Figure 1; their physical dimensions and component weights are listed in Table 1.

Table 1

Approximate Values for Selected Characteristics of the Four Backpacks

Backpack	Length* (cm)	Width* (cm)	Depth* (cm)	Frame and Bag Weight** (kg)
ALICE LC-2	52	46	40	3.23
ALICE LC-1	51	46	39	2.84
LOCO	61	35	30	1.41
PACKBOARD	54	46	32	3.57

* Dimensions were measured with the pack loaded with the basic 9.1 kg load (Load 4) which consisted of a sleeping bag, mattress, waterproof clothes bag, poncho, socks, and undershirt. The length and width dimensions were the greatest values for the frame-pack systems in their respective directions. The depth dimension was an estimate of the maximum distance the pack projected from the body.

** Combined weight when empty.

Figure 1. Four Backpack Systems: A - ALICE LC-2; B - ALICE LC-1; C - LOCO; D - PACKBOARD.

Load Conditions

A careful selection of loada was made to cover a wide range of typical military loads. In addition, a minimal load condition was added to provide baseline performance data for comparative purposea. The other loads represented systematic increases. In all, there were six different loads. The male subjecta performed under all six load conditions while the female subjecta were excluded from Load 6. The following is a general description of the six loads. Additional information on the clothing and equipment comprising the loada is presented in Appendix A and in Ref. 1.

Load 1 served as the baseline condition. Subjects wore shorts, socks, t-shirt, and sneakers.

Load 2 was considered the fighting gear condition. The subjects wore underwear, socks, utility shirt and trousers, boots, and the standard, ALICE fighting gear which included a water-filled canteen with cover, intrenching tool with carrier, and two small arms ammo cases containing 1.75 kg sandbags.

Load 3 was deaignated the combat gear condition. The subjects wore a PASGT helmet and armor vest and carried a simulated M-16 rifle in addition to those items included in Load 2.

Load 4 included all items from Load 3 plus one of the four frame-pack combinations containing a 20-pound (9.1 kg) load. This load consisted of a sleeping bag, mattress, waterproof clothes bag, poncho, socks, and undershirt.

Load 5 included all items from Load 4 plus an additional weight of 15 pounds (6.8 kg) placed in the pack. The extra load consisted of three, 5-pound (2.3 kg) barbell disks.

Load 6 was carried by the men only and included all items from Load 4 plus 30 additional pounds (13.6 kg) in the form of three, 10-pound (4.5 kg) disks placed in the pack.

Because of the differences in the weights of the frames, the weight varied among the backpacks for Load Conditions 4 to 6. Furthermore, the number of subjects differed slightly for the standing and jumping tests. The mean values for all loads and backpacks for men and women for the two movements are presented in Tables 2 and 3.

Table 2

Mean Load Valuea (kg) for Men and Women for Easy Standing

BACKPACK	LOAD 1	2	3	4	5	6
MEN (N=14)	.75	9.40	17.49			
ALICE LC-2				29.83	36.63	43.44
ALICE LC-1				29.42	36.22	43.03
LOCO				27.97	34.77	41.58
PACKBOARD				30.15	36.95	43.76
LOAD MEAN				29.34	36.14	42.95
WOMEN (N=11)	.56	9.04	16.92			
ALICE LC-2				29.26	36.06	
ALICE LC-1				28.85	35.65	
LOCO				27.40	34.20	
PACKBOARD				29.58	36.38	
LOAD MEAN				28.77	35.57	

Table 3

Mean Load Values (kg) for Men and Women for Vertical Jump

BACKPACK	LOAD 1	2	3	4	5	6
MEN (N=11)	.73	9.41	17.54			
ALICE LC-2				29.88	36.68	43.49
ALICE LC-1				29.47	36.27	43.08
LOCO				28.02	34.82	41.63
PACKBOARD				30.20	37.00	43.81
LOAD MEAN				29.39	36.19	43.00
WOMEN (N=10)	.58	9.04	16.95			
ALICE LC-2				29.29	36.09	
ALICE LC-1				28.88	35.68	
LOCO				27.43	34.23	
PACKBOARD				29.61	36.41	
LOAD MEAN				28.80	35.60	

EASY STANDING

This test was used as a measure of postural stability under the influence of the different loads and backpacks. The subject stood on the force platform as motionless as possible during the test interval. The test utilized the sophistication of the laboratory force platform (Kistler, Model 9261A and on-line computer (PDP Model 11-34) systems shown in schematic form in Figure 2. The data acquisition program sampled F_z, M_x and M_y for ten seconds at 50 H_z. By dividing the moments by F_z, the X, Y coordinates for the center of pressure location were obtained for each of the 500 samples. These data were then smoothed using a 5-point moving average technique. The experimental data were the accumulated absolute displacements in the X direction, denoted CPX, and representing anterior-posterior movement; the Y direction, CPY, reflecting medial-lateral motion; and the vectoral sum of these, referred to as the total excursion, CPT. These values were measured in units of meters, but are included here in centimeters for ease of presentation and compatibility with previous research (Ref. 2 and 3).

Subjects and Experimental Design

A total of 25 students, 14 men and 11 women, all undergraduates enrolled in the University Army R.O.T.C. program, served as subjects. They were a subset of the 30 subjects, representative of military personnel, who completed the first study in this series (Ref. 1). Descriptive data for these subjects are presented in Table 4.

Table 4

Physical Characteristics of Subjects in Easy Standing Test

Gender	N	Age (yrs)		Height (cm)		Weight (kg)	
		$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Men	14	20.8	1.8	175.0	7.6	69.2	7.4
Women	11	20.7	1.6	166.4	4.8	60.8	10.9

(Characteristics)

The data collection for easy standing was carried out in one test session. All subjects completed three trials under each condition. The first three load conditions were presented to the subjects in sequential fashion beginning with Load 1. Thereafter, the order of backpacks was randomly assigned and all load conditions (assigned at random) were completed once a specific backpack was placed on the subject.

Because of the complexity in experimental design, it was necessary to conduct the data analysis in three parts. The first dealt with the comparison of male and female performance under the first three load conditions. Part two, based on performance under Loads 4 and 5, involved a comparison of men and women and evaluation of the four backpacks. In part three, the effects of load and backpack on male performance for Loads 4, 5, and 6 were investigated.

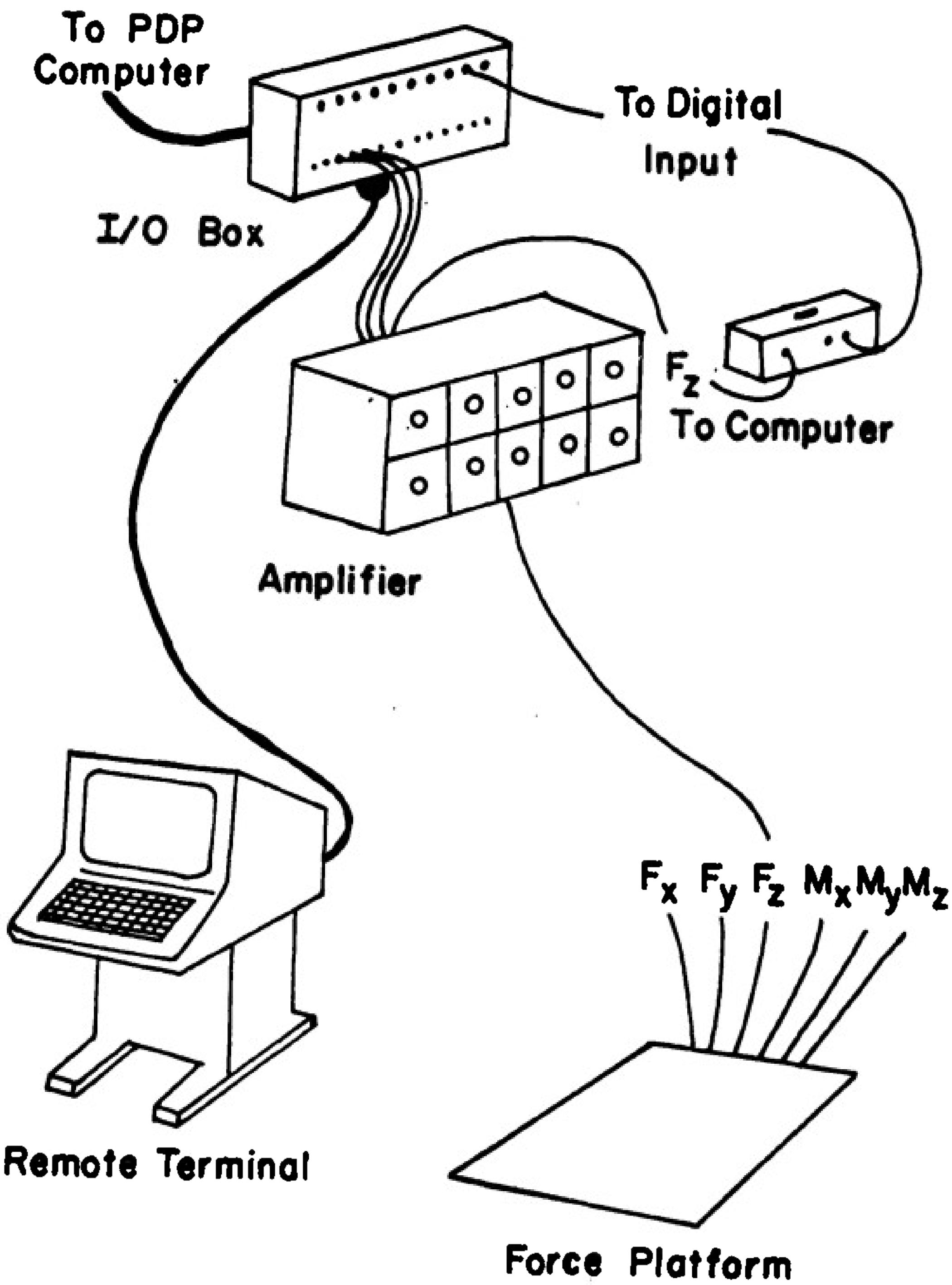

Figure 2. On-Line System for Force Platform Measurements.

Teat Procedures

The subject was instructed to step onto the force platform, assume a self-determined, comfortable stance, focus on an "X" marked on the curtain in front of him, and maintain a atsble body position for a ten-second period. The subject placed his srms at his sides for Loads 1 and 2 snd held the rifle in both hands in front of the body for Loads 3 to 6. The data were recorded on disc and the calculated values were displayed on a terminal and printed on a line printer. Trials were repeated at one-minute intervals until three were completed for a given experimental condition. The subject then changed the load according to the prescribed order and continued the test procesa. Figure 3 shows a subject on the force platform undergoing the easy standing test.

Results

Test Reliability. Trial-to-trial relisbility coefficients were determined aeparately for the men and the women as a means of asaessing the reproducibility of the experimental variables. Tables 5 and 6 contain a summary of the results of this analyais. Table 5 contains the frequencies of the reliability coefficienta at 0.10 intervals across all six loads for all three variables. A total of 18 coefficients was calculated for Loads 1, 2, and 3; 72 coefficients for Loads 4 and 5; and 36 coefficients for Load 6, resulting in a total of 234 coefficients. Of this number 80% were above 0.70 and 58% were above 0.80.

Table 5

Frequencies of Trial-to-Trial Reliability Coefficients for Men and Women under All Test Conditions

		RELIABILITY COEFFICIENTS					
Load	Number of Coefficienta	<0.50	0.50	0.60	0.70	0.80	0.90
1	18	1	1	4	5	6	1
2	18	2	1	3	7	3	2
3	18	3	1	1	1	6	6
4	72	1	6	6	18	26	15
5	72		3	7	15	34	13
6	36		2	6	6	11	11
TOTALS	234	7	14	27	51	86	48
% of Total		3%	6%	12%	22%	37%	21%

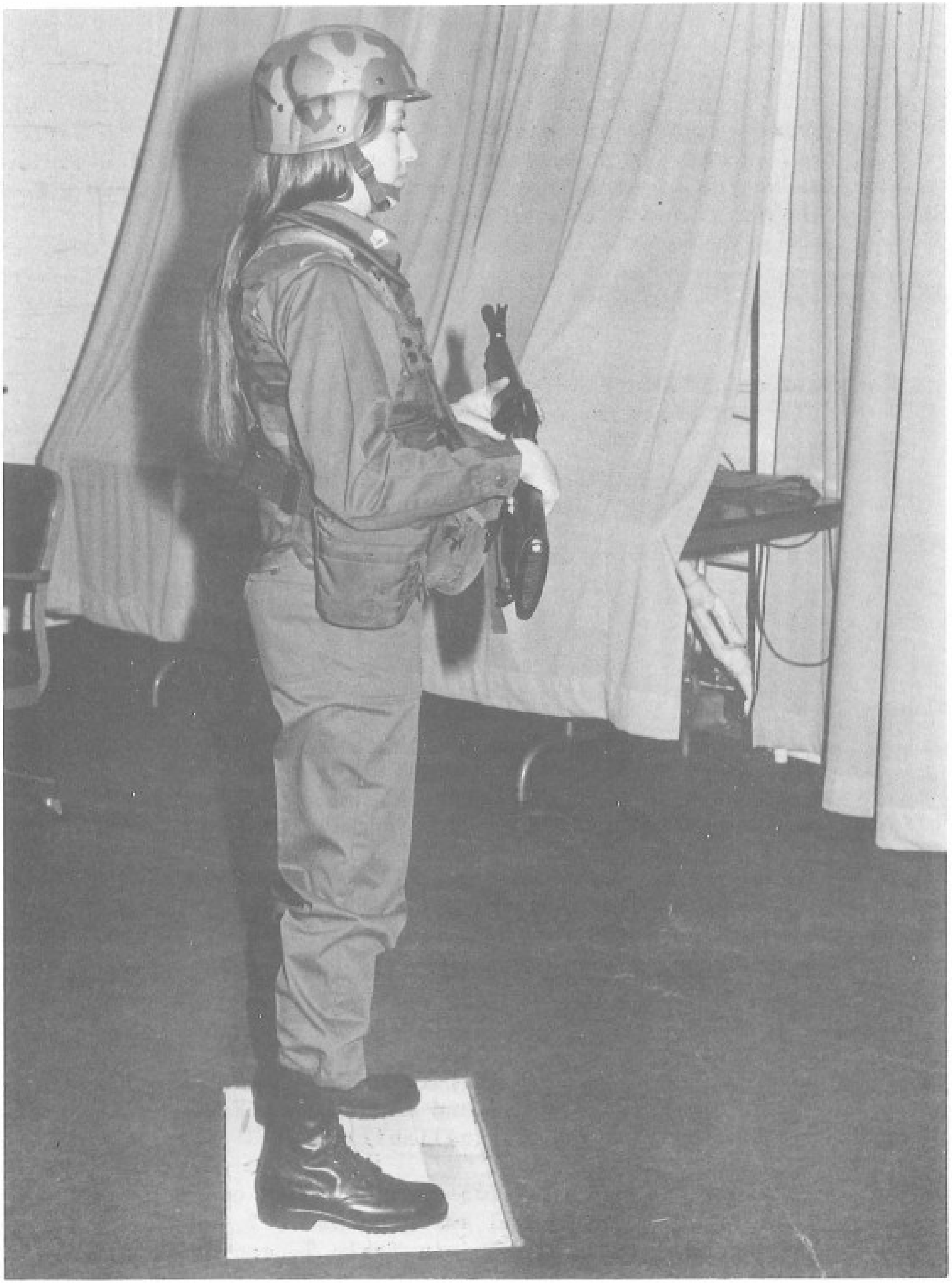

Figure 3. Subject Performing Easy Standing Test.

A further analysis was carried out based only on the trials in which a pack was worn. These results are shown in Table 6. A total of 180 coefficients, 45 for each Backback condition, are presented. Since these coefficients represent a major portion of the total presented in Table 5, the overall results are the same. It is interesting to note the similarity in frequencies for the first three Backpacks, while the PACKBOARD demonstrated considerably higher reliability coefficients.

Table 6

Frequencies of Trial-to-Trial Reliability Coefficients for Men and Women under Four Backpack Conditions

Backpack	Number of Coefficients	RELIABILITY COEFFICIENTS 0.50	0.60	0.70	0.80	0.90
ALICE LC-2	45	3	5	11	20	6
ALICE LC-1	45	4	6	10	20	5
LOCO	45	4	8	10	18	5
PACKBOARD	45	3	3	7	10	22
TOTALS	180	13	22	38	68	38
% of Total		7%	12%	21%	38%	21%

Dependent *t*-tests were also calculated as a means of assessing any changes in mean performance which may have occurred from trial to trial. Of the 234 *t*-tests, only 28 were statistically significant at the .05 level. Considering the large number of *t*-ratios calculated and the lack of independence in multiple comparisons of three trials, it was evident that the mean performance was relatively stable from trial to trial for all experimental variables. Overall, it was concluded that, under the variety of test conditions, the coefficients obtained and mean comparisons conducted indicated an acceptable level of test reliability.

Effects of Gender and Load. A two-way ANOVA was used to evaluate the differences between men and women and among Loads 1, 2, and 3 for CPX, CPY, and CPT. The mean values are presented in Table 7, and ANOVA summaries are included in Appendix B.

Table 7

Mean CPX, CPY, and CPT Values for Gender and Load

MAIN EFFECT	CPX(cm)	CPY(cm)	CPT(cm)
GENDER			
MEN (N=14)	5.89*	4.77	8.66
WOMEN (N=11)	6.94	4.93	9.48
LOAD			
1	6.62	5.23	9.53
2	6.16	4.70	8.78
3	6.29	4.59	8.76

*Means not connected by vertical lines are significantly different (P<.05).

A tendency for greater stability (lower values) on the part of the men was present, but the differences were not significant. Load differences were present for CPY and CPT whereby Loada 2 and 3 were similar but both differed significantly from Load 1. No significant interactions between Gender and Load were present. Less body motion was observed for the heavier load conditions. Further, use of the armor vest, helmet and M-16 rifle in Load 3 did not increase the CP values above those for Load 2. This is partly explained by the distribution of the added load close to the body of the subject. A consistent pattern of higher CPX than CPY values can be obaerved. This was due to the placement of the additional load primarily on the anterior and posterior surfaces of the body.

Effecta of Gender, Load, and Backpack. A three-way ANOVA was utilized to evaluate the influence of Gender, Load and Backpack on postural stability. The mean values are presented in Table 8.

Table 8

Mean CPX, CPY, and CPT Values for Gender, Load, and Backpack

MAIN EFFECT	CPX(cm)	CPY(cm)	CPT(cm)
GENDER			
MEN	5.37	4.55	5.05
WOMEN	7.14	5.70	10.32
LOAD			
4	5.92	4.79	8.65
5	6.38	5.32	9.45
BACKPACK			
ALICE LC-2	6.31	5.12	9.23
ALICE LC-1	5.33	5.19	9.30
LOCO	5.79	4.76	8.51
PACKBOARD	6.17	5.15	9.15

None of the interactions were significant. The male subjects showed greater stability for all three measurements, however, only the mean difference for CPT was significant. Differences between Load means for all three parameters were significant with the higher values associated with the greater load. The significant differences among the packs were due to the lower values for the LOCO pack. None of the differences among the other three packs were significant. For CPX and CPY the LOCO pack differed significantly from two of the other three backpacks while for CPT it differed from all three. The LOCO pack allows for the load to be positioned closer to the body which probably accounts for the greater postural stability.

Effects of Load and Backpack. As a means of utilizing the Load 6 data for men, a two-way ANOVA involving Load and Backpack was carried out. These results appear in Table 9.

Table 9

Mean CPX, CPY, and CPT Values for Load and Backpack for Men

MAIN EFFECT	CPX(cm)	CPY(cm)	CPT(cm)
LOAD			
4	5.27	4.37	7.82
5	5.48	4.74	8.28
6	5.76	5.14	8.81
BACKPACK			
ALICE LC-2	5.62	4.96	8.58
ALICE LC-1	5.70	4.79	8.52
LOCO	5.26	4.36	7.77
PACKBOARD	5.44	4.88	8.35

The Load X Backpack interaction was not significant indicating similar performance across the load-pack combinations. Postural stability decreased as the load increased with significant differences noted between Loads 4 and 6 for CPY and CPT. The backpack results tended to favor the LOCO pack for all three variables, but it differed significantly only from the ALICE LC-2 for CPT. Previous studies have demonstrated less body movement for the LOCO pack in comparison with external frame systems (Ref. 3).

Comparative Analysis of Load Effects. Because of the variety of load and backpack conditions, it was not possible to evaluate their effects in one statistical treatment. The three lower loads offer similar conditions, but Loads 4 and 5 were influenced by the variability among the four frame-pack systems, while the females were not tested under Losd 6. In an attempt to assess the overall effect of load on postural stability, mean values were obtained for each condition. These are presented numerically in Table 10 and graphically in Figures 4 and 5. In the case of Loads 4, 5, and 6, the data from sll four backpacks have been used to calculate the Load mean.

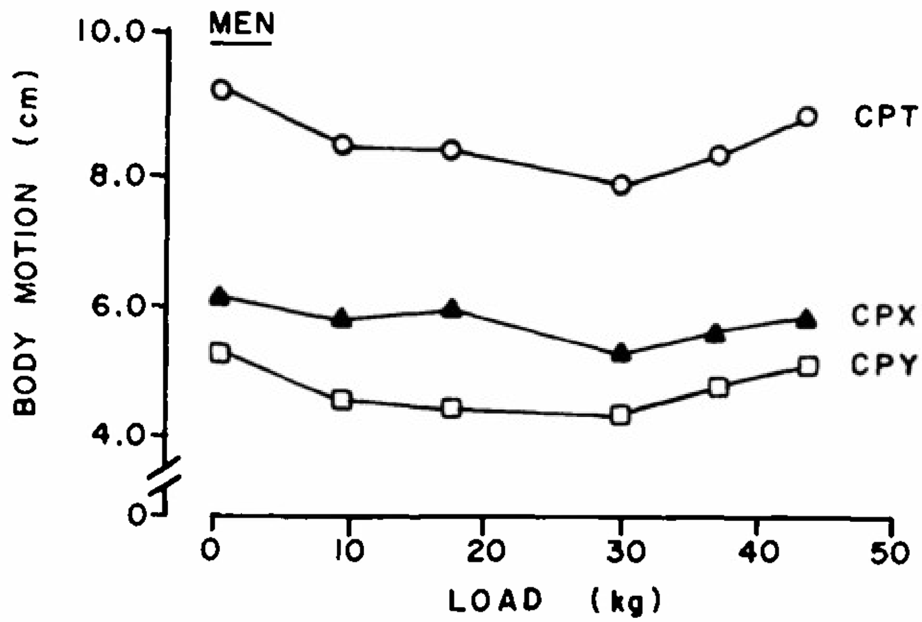

Figure 4. Mean CPX, CPY, and CPT Values for Men under Six Load Conditions.

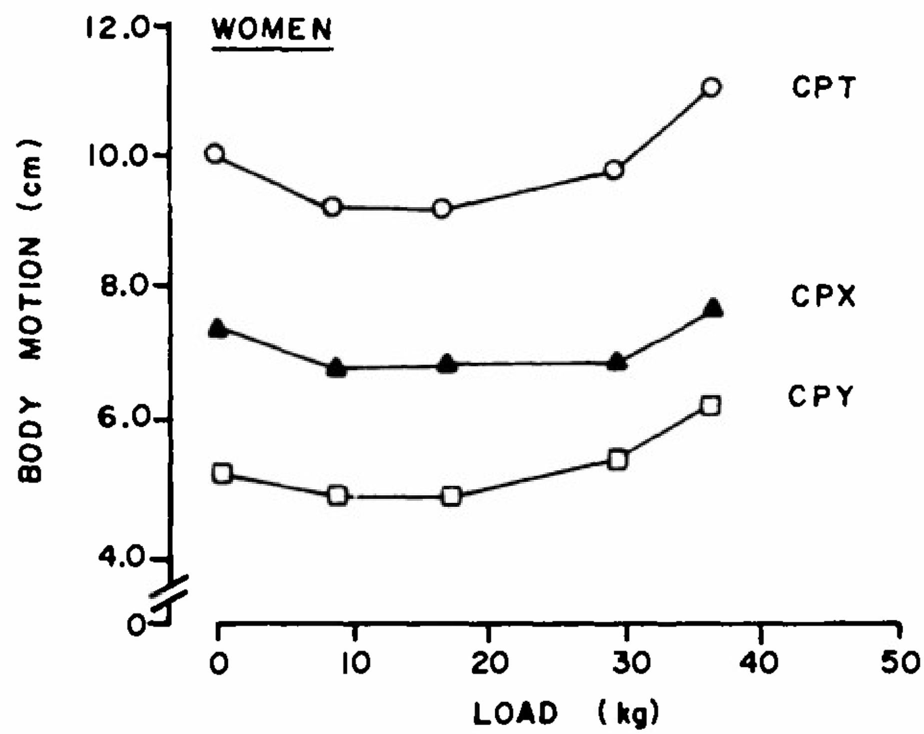

Figure 5. Mean CPX, CPY, and CPT Values for Women under Five Load Conditions.

Table 10

Mean Values of CPX, CPY, and CPT for Men and Women

GENDER	VARIABLE	1	2	3	4	5	6
MEN							
(N=14)	CPX(cm)	6.05	5.75	5.88	5.27	5.48	5.76
	CPY(cm)	5.30	4.59	4.43	4.37	4.74	5.14
	CPT(cm)	9.18	8.45	8.36	7.82	8.28	8.81
WOMEN							
(N=11)	CPX(cm)	7.34	6.67	6.80	6.75	7.53	
	CPY(cm)	5.15	4.84	4.80	5.32	6.07	
	CPT(cm)	10.0	9.20	9.26	9.69	10.94	

The data indicate a non-linear pattern across the load conditions with a tendency for greater stability to occur at the middle loads. This U-shaped pattern suggests that, when relatively light loads are added close to the body, they result in diminished body sway in comparison to the unloaded condition. As the load is increased further, it becomes increasingly more difficult to maintain postural stability. The additional weights for Loads 5 and 6 were placed in a section of the bag close to the posterior surface of the body. As a result, the effect of these added loads was probably less than if the weight had been placed in the bag further from the body.

Summary. The men tended to be more stable in their easy standing posture than the women. This was most evident for CPT under Loads 4 and 5. Both men and women demonstrated greater stability for the medium loads with the lighter and heavier loads producing similar values. The main difference among the frame-pack systems was attributed to greater stability for the LOCO pack. Since this backpack, which is lighter than the others, utilizes an elongated internal frame system, the pack load is located closer to the body which probably accounts for its advantage on this type of test.

VERTICAL JUMP

The maximal vertical jump test represents a fundamental human movement which has relevance to the foot soldier in combat. Furthermore, it is relatively easy to standardize in the laboratory environment and has been shown to be a reliable performance test in previous load carrying studies (Refs. 2 and 3). It is well suited for the purposes of the present study; namely, to compare male and female performance, evaluate the effects of increased load, and compare various frame-pack syatems.

The force platform and laboratory computer systems used for Easy Standing were also used for the Vertical Jump Tests. The vertical ground reaction force, Fz, was sampled at a rate of 833 Hz as the aubject executed

the vertical jump from the force platform. The height of the jump represented by the vertical displacement of the center of gravity was obtained by converting the force-time data to acceleration-time data which was then subjected to double integration. A computer program which utilized the basic force-time data was used to calculate the force, temporal and height of jump parameters.

Subjects and Experimental Design

The subjects for these jumping tests were 11 men and 10 women who had participated in the Easy Standing Test as well as the first study in this series (Ref. 1). Descriptive data for them are presented in Table 11.

Table 11

Physical Characteristics of Subjects in Vertical Jump Test

GENDER	N	Age (yrs)		Height (cm)		Weight (kg)	
		$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Men	11	21.0	1.8	174.6	5.4	70.3	7.9
Women	10	21.0	1.6	166.2	5.0	61.6	11.2

Data collection for this test required two test sessions. Four trials for each load condition were completed with the mean of the best three, based on height of jump, used in the data analysis. Both test sessions began with Load Conditions 1, 2, and 3 which were presented in sequential order. Two trials of each condition were performed on each test day. The backpacks were randomly assigned for Load Conditions 4 and 5 with subjects completing four trials of one of the two load conditions each test day. In addition, the men completed four trials of Load Condition 6 for two of the four backpacks each test day. However, Load 6 was always paired with Load 4 to avoid having the subject perform with the two heaviest loads in the same session. This protocol was established as a means of distributing the trials uniformly across the two days and also to minimize the effects of fatigue which could have adversely affected the results.

Test Procedures

The subject was instructed to perform some stretching exercises and a limited number of warmup jumps. In addition, one practice jump was completed as each new experimental condition was introduced. The subject was then asked to step onto the force platform and assume a comfortable stance. A verbal signal of "jump" was given as the experimenter activated the measurement

system. This signal informed the subject that he must initiate his jump within two seconds, but was not considered a starting signal. The vertical jump was carried out with a countermovement and a maximal effort requested for each trial. A one-minute rest between trials was provided. The holding of the M-16 weapon in Conditions 3 to 6 restricted the normal arm swing movement associated with maximal vertical jumping. In an attempt to standardize the movement for all conditions, the subjects held a light broom stick during the tests for Loads 1 and 2. Observation of the subjects during the experiments indicated similar arm patterns were employed for all Load Conditions. Figure 6 shows a subject executing the vertical jump movement.

Experimental Variables

Figure 7 shows a typical vertical ground reaction force during a jumping trial. The body weight of the subject served as a baseline as he stood on the force platform prior to initiating the jumping movement. The main features of the force-time curve are the unweighting phase which occurs during the first part of the downward movement, the peak positive force above the zero baseline (B), and the time of postive force application (A). Vertical displacement (jump height) was calculated by double integration of the force curve which is directly related to the acceleration of the center of gravity of the body. In addition to these three parameters, two ratios involving the peak force were calculated. The denominators for these ratios were body weight of the subject and system weight which included body weight and all additional load. The specific parameters used in the data analysis were as follows: (1) time of positive force application, (2) peak force, (3) peak force/body weight, (4) peak force/system weight, and (5) height of jump. All of these were calculated via programs processed by the laboratory computer from the data collected during each trial. This on-line computer system made it possible to complete the numerous jumping trials performed in this study.

Results

Effects of Gender and Load. This part of the analysis involved the comparison of men and women and the effects of Loads 1, 2, and 3. The basis for these comparisons were the five vertical ground reaction force parameters described in the previous section. The mean values and statistical results are presented in tabular form for each parameter. In addition, complete ANOVA summaries are included in Appendix C. The mean values for time of force application are presented in Table 12.

Table 12

Mean Time (msec) of Force Application for Gender and Load

GENDER	LOAD 1	LOAD 2	LOAD 3	GENDER $\bar{X}$
Men (N=11)	403	418	448	422*
Women (N=10)	321	338	374	345
LOAD $\bar{X}$	364	380	413	

*Means not underlined or connected by vertical lines are significantly different (P<.05).

Figure 6. Subject Performing Vertical Jump Test.

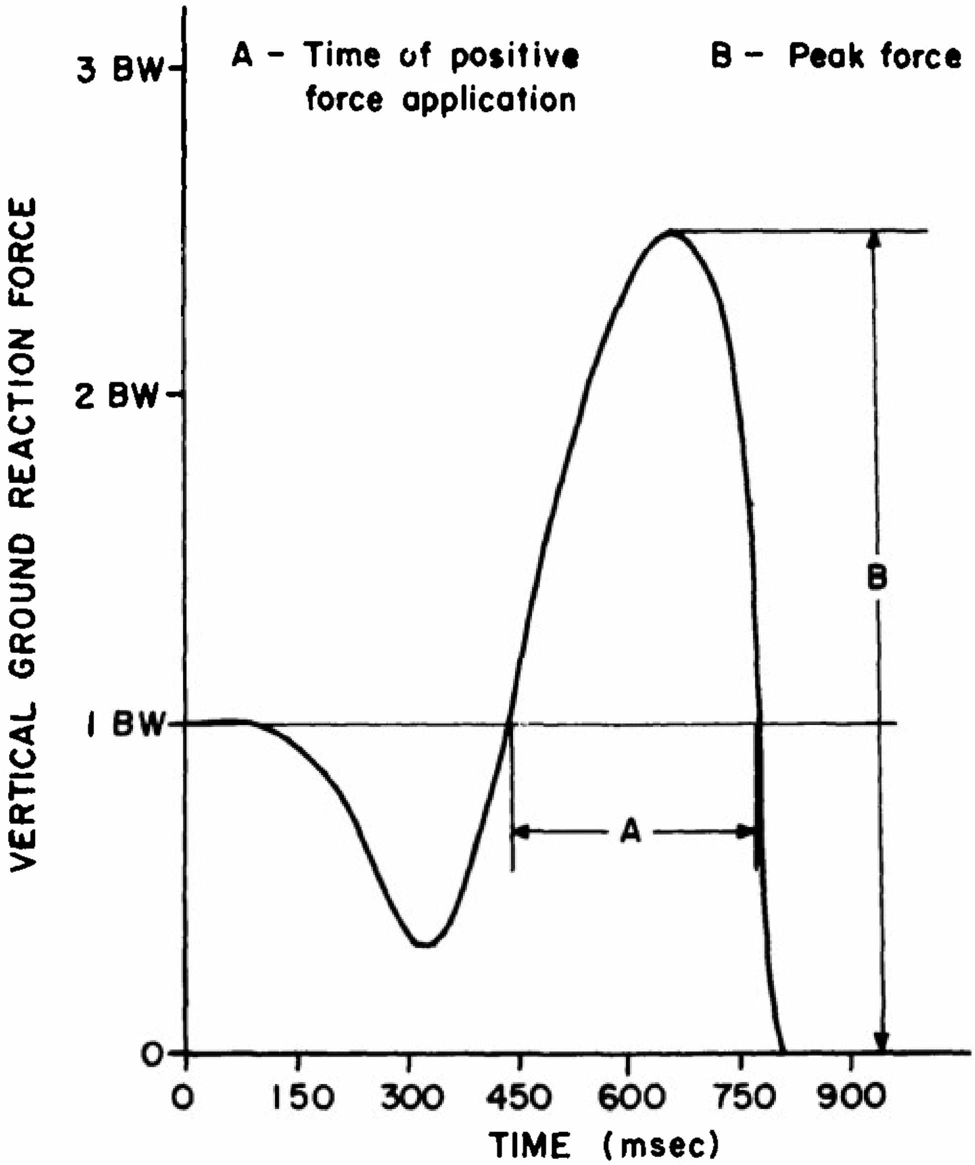

Figure 7. Typical Ground Reaction Force-Time Curve during a Vertical Jump

The men demonstrated significantly longer times (F = 5.4) than their female counterparts during the positive phase of force application. The mean for the women was 82% of that for the men. The Gender x Load interaction was not significant while the main effect of Load was significant (F = 34.2). The greater load led to a significantly longer time of force application.

The mean values for the second variable, peak force, are contained in Table 13.

Table 13

Mean Peak Force Values (Newtons) for Gender and Load

GENDER	LOAD 1	LOAD 2	LOAD 3	GENDER $\bar{X}$
Men	1791	1832	1902	1841
Women	1524	1594	1596	1571
LOAD $\bar{X}$	1663	1719	1756	

The main effects for Gender (F = 4.7) and Load (F = 11.1) were significant, but not their interaction (F = 1.5), thereby precluding internal comparisons of loads at each level of gender. The larger peak forces for the men were expected on the basis of their greater body weight since the peak force was measured from the zero baseline. It is of interest to note that the mean peak force for women was about 85% that of the men, while their mean body weight was also 85% of the male value. This indicates that the peak forces produced were in direct proportion to the body weights of the subjects. Load 1 differed from the other two, but Loads 2 and 3 were not significantly different from each other. The reason for this can be seen in the mean values for women, which were nearly identical for Loads 2 and 3. The men, to the contrary, showed clear differences between all adjacent loads.

As a means of compensating for differences in subject body weight, peak forces relative to body weight were calculated. The mean values are shown in Table 14.

Table 14

Mean Peak Force Relative to Body Weight for Gender and Load

GENDER	LOAD 1	LOAD 2	LOAD 3	GENDER $\bar{X}$
Men	2.54	2.60	2.71	2.62
Women	2.46	2.59	2.60	2.55
LOAD $\bar{X}$	2.51	2.60	2.66	

These results revealed no differences in the ratios of peak force to body weight between men and women (F = 0.31). This indicates that the peak force produced during the takeoff movement tends to be related to body weight as previously noted. The ratios across the three loads showed increased values but the only significant difference was between Load 1 and Load 3 (F = 15.4). The similar performance of the women under Loads 2 and 3 was the main factor in diminishing the total group mean difference. The Gender x Load interaction was not significant (F = 1.37), hence, no comparisons of load by gender were carried out.

Another approach to the evaluation of peak takeoff force in jumping is to calculate the force relative to system weight based on the sum of body weight and added load. Table 15 contains the mean values for this parameter.

Table 15

Mean Peak Force Relative to System Weight for Gender and Load

GENDER	LOAD 1	2	3	GENDER $\bar{X}$
Men	2.54	2.30	3.22	2.35
Women	2.46	2.27	2.04	2.26
LOAD $\bar{X}$	2.51	2.29	2.13	

Differences between men and women were not significant (F = 0.78) but load differences (F = 120.1) and the Gender x Load interaction (F = 4.45) were significant. Internal analysis revealed that load differences for each gender were all significant. Examination of the means indicated that the male ratios showed the greatest decrease from Load 1 to 2, but those for the females from Load 2 to 3. It might have been expected that the mean values across loads would be similar under the assumption that the increased load would precipitate proportionately greater peak forces. Actually the peak forces did not increase at the same rate as the added external load.

The fifth variable under investigation was the height of jump, the most important practical variable since it relates directly to performance of soldiers in the field. The means are contained in Table 16.

Table 16

Mean Values of Height of Jump (cm) for Gender and Load

GENDER	LOAD 1	2	3	GENDER $\bar{X}$
Men	44.8	38.3	36.4	29.8
Women	31.8	26.2	23.3	27.1
LOAD $\bar{X}$	38.6	32.5	30.2	

The Gender difference was significant (F = 86.9) as was that for Load (F = 116.7), while the interaction was not (F = 0.33). The latter result dictated that no internal load comparisons be made. These results, showing better male performance, are similar to those obtained in the combative movement tests (Ref. 1). Overall, the female performance was 68% of the male performance with a steady decrease in relative performance across the loads. The female percentage of male performance for Loads 1, 2 and 3 were 71, 68 and 64%, respectively, which indicated the added load had a greater effect upon female performance. The significant decrease in performance with increased load was to be expected. However, the drop between Loads 1 and 2 (6.5 cm) was considerably greater than from Loads 2 to 3 (2.3 cm).

Effects of Gender, Load, and Backpack. This part of the experimental work involved analysis of maximal vertical jumps performed by the subjects while they wore each of four different backpacks under two different load conditions. A three-way ANOVA was used to evaluate the differences between the main effects and their interactions. The mean values for the five parameters are presented in tabular form and complete ANOVA summaries can be found in Appendix C. Table 17 contains the mean values for time of force application.

Table 17

Mean Time (msec) of Force Application for Gender, Load, and Backpack

MAIN EFFECT	TIME
GENDER	
Men	494
Women	412
LOAD	
4	442
5	467
BACKPACK	
ALICE LC-2	462
ALICE LC-1	454
LOCO	445
PACKBOARD	458

The only significant main effect was for Load (F = 19.6) with the greater load resulting in longer time of force application. The mean time for men was greater than for women, but the difference was not significant. None of the interactions were significant, nor were any differences among the backpacks of importance.

The results for peak force, shown in Table 18, revealed significantly higher values for men (F = 7.3) and Load 5 (F = 111.3). No differences were observed among the four frame-pack systems nor were any of the interactions significant.

Table 18

Mean Peak Force (Newton) for
Gender, Load, and Backpack

MAIN EFFECT	TIME
GENDER	
Men	2032
Women	1708
LOAD	
4	1848
5	1908
BACKPACK	
ALICE LC-2	1879
ALICE LC-1	1886
LOCO	1861
PACKBOARD	1884

The means for peak force/body weight are presented in Table 19.

Table 19

Mean Values of Peak Force/Body
Weight for Gender, Load, and Backpack

MAIN EFFECT	PEAK FORCE/BODY WT.
GENDER	
Men	2.90
Women	2.79
LOAD	
4	2.80
5	2.89
BACKPACK	
ALICE LC-2	2.85
ALICE LC-1	2.86
LOCO	2.82
PACKBOARD	2.86

The only significant main effect was for Load with Load 5 having a greater mean value. The mean values for the four packs were very similar.

Further analysis involved the calculation of peak force/system weight ratios, the results of which are shown in Table 20.

Table 20

Mean Valuea of Peak Force/Syatem Weight for Gender, Load and Backpack

MAIN EFFECT	PEAK FORCE/SYSTEM WT.
GENDER	
Men	?.20
Women	1.85
LOAD	
4	1.98
5	1.90
BACKPACK	
ALICE LC-2	1.93
ALICE LC-1	1.95
LOCO	1.95
PACKBOARD	1.92

The main effect for Gender was not significant (F = 3.17) even though the men demonstrated somewhat higher values. The Load effect (F = 106.5) and its interaction with the packs (F = 3.36) were significant. Internal analysis indicated that all four packs showed significantly different means for the two Load Conditions with higher values for Load 4. Further evaluation revealed that for Load 4, the ALICE LC-1 was significantly greater than the PACKBOARD. However, for Load 5, the LOCO was significantly greater than the ALICE LC-2. These differences were quite small and are considered to be of limited importance.

The results for height of jump are contained in Table 21.

Table 21

Mean Values of Height of Jump (cm) for Gender, Load, and Backpack

MAIN EFFECT	HEIGHT OF JUMP
GENDER	
Men	29.8
Women	19.9
LOAD	
4	26.1
5	24.1
BACKPACK	
ALICE LC-2	24.8
ALICE LC-1	24.8
LOCO	26.0
PACKBOARD	24.9

All three main effects, Gender (F = 54.1), Load (F = 118.3), and Backpack (F = 3.0) as well as the Gender x Load interaction (F = 10.1) were significant. The men jumped 9.9 cm higher than the women and both groups performed more poorly under Load Condition 5. Internal analyses indicated that differences among all combinations of Gender and Load were significant. The only significant Backpack differences were between the LOCO which was found to be superior to the two ALICE systems.

Effects of Load and Backpack. The inclusion of Load 6 for the male subjects made it possible to carry out a third analysia in which differences among the four backpacks and three loads were evaluated. A two-way ANOVA was used for this purpose. The mean values for all five ground reaction force parameters are summarized in Table 22. The complete ANOVA results are contained in Appendix C.

Table 22

Mean Ground Reaction Force Parameters for Backpack and Load

			PARAMETER		
MAIN EFFECT	TIME OF FORCE (msec)	PEAK FORCE (N)	PEAK FORCE/ BODY WT.	PEAK FORCE/ SYSTEM WT.	HEIGHT OF JUMP (cm)
BACKPACK					
ALICE LC-2	511	2,056	2.93	1.97	28.8
ALICE LC-1	493	2,064	2.96	1.99	28.1
LOCO	498	2,036	2.89	1.99	29.7
PACKBOARD	503	2,067	2.94	1.97	28.4
LOAD					
4	480	2,002	2.86	2.06	31.1
5	507	2,062	2.94	1.98	28.6
6	516	2,103	3.00	1.90	26.6

These results for the backpacks support those reported in the previous section. There are no significant differences among the packs with the exception of height of jump where the LOCO pack differed from the ALICE LC-1 and the PACKBOARD. Even in this case, the mean differences are less than 2 cm. These frame-pack syatems are apparently so similar that the mean jumping performance of the men was not altered as a function of the backpack worn.

The effect due to increased load is far more pronounced with systematic differences noted across the three loads for all variables. In three cases, the differences between Loada 4 and 5 were not significant. However, for the two primary parameters, peak force and height of jump, all three loads differed significantly.

Comparative Analysis of Load Effects. The experimental design used in this experiment precluded statistical treatment across all loads. This was due to the inclusion of the four frame-pack systems in the evaluation of

gender, load, and backpack under Load Conditions 4 and 5. By combining the results obtained for the four backpack conditions, it is possible to establish mean values for each load for men and women. This approach was used to examine the effects of increased load on the five vertical jumping parameters. The means for men and women for these parameters are included in Table 23 and shown graphically in Figures 8-12.

Table 23

Mean Vertical Jump Parameters for Men and Women under All Load Conditions

Parameter	Gender	LOAD 1	2	3	4	5	6
Time of Force Application (msec)	Men	403	418	448	480	507	516
	Women	321	338	374	400	423	
Peak Force (N)	Men	1791	1832	1902	2002	2062	2103
	Women	1524	1594	1596	1679	1739	
Pk. F/B.W.	Men	2.54	2.60	2.71	2.86	2.94	3.00
	Women	2.46	2.59	2.60	2.73	2.84	
Pk. F/S.W.	Men	2.54	2.30	2.22	2.06	1.98	1.90
	Women	2.46	2.27	2.04	1.89	1.81	
Ht. of Jump (cm)	Men	44.8	38.3	36.4	31.1	28.6	26.6
	Women	31.8	26.2	23.3	20.6	19.1	

These data provide insight into the changes in the ground reaction force components which accompany increases in the load being carried by the performer while executing the vertical jump movement. The mean values for time of force application depicted in Figure 8 show a linear increase with load. The greater load adds to the inertia of the system which necessitates more time to accelerate the body upward.

The peak force values (Figure 9) increase linearly with increments of load. This would be expected since peak force was measured from the zero baseline. Consequently, the initial force level during standing was elevated above body weight due to the added load. It would be of interest to compare the increase in peak force with the added load converted to force units of newtons. This was accomplished by comparing the increases in force and load across adjacent load conditions. That is, the changes from Load 1 to 2, Load 2 to 3, etc. Table 24 contains these data and the percentage values of force to load.

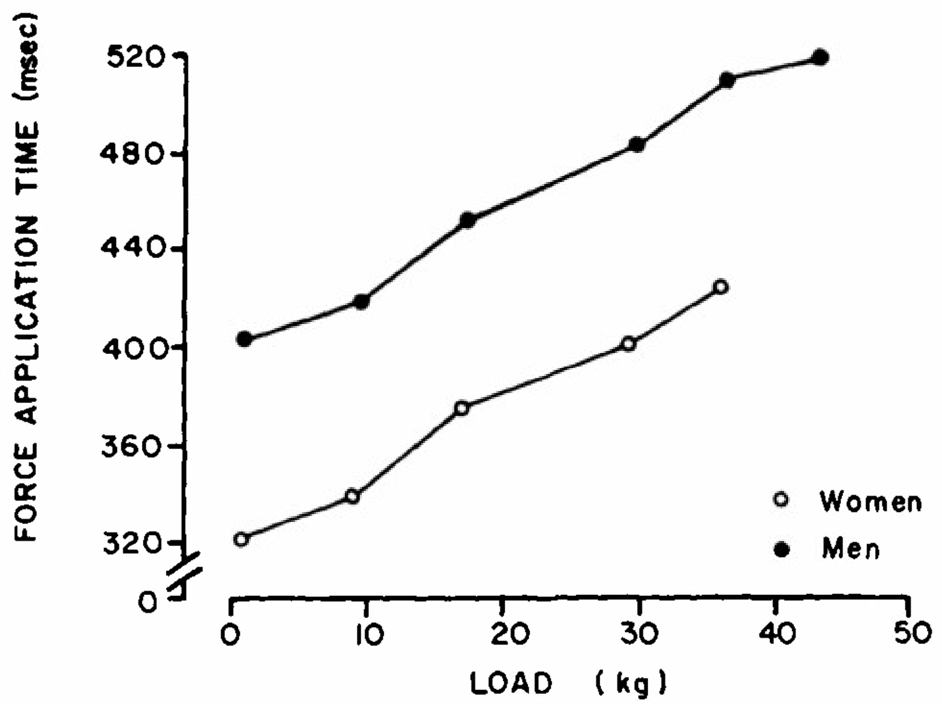

Figure 8. Mean Time of Force Application for Men and Women under Experimental Load Conditions.

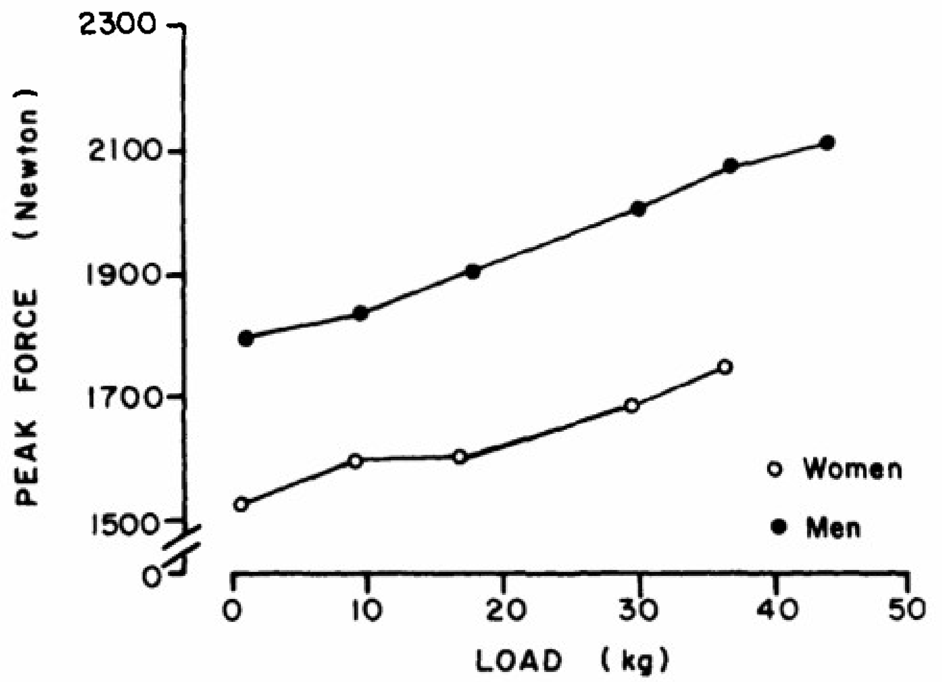

Figure 9. Mean Peak Force for Men and Women under Experimental Load Conditions.

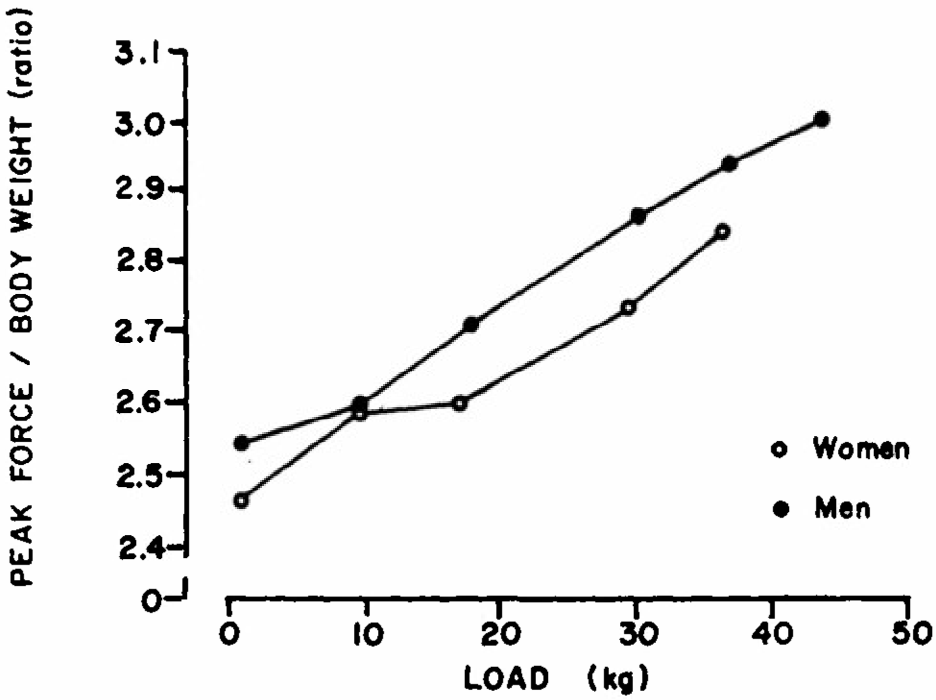

Figure 10. Mean Peak Force/Body Weight Ratios for Men and Women under Experimental Load Conditions.

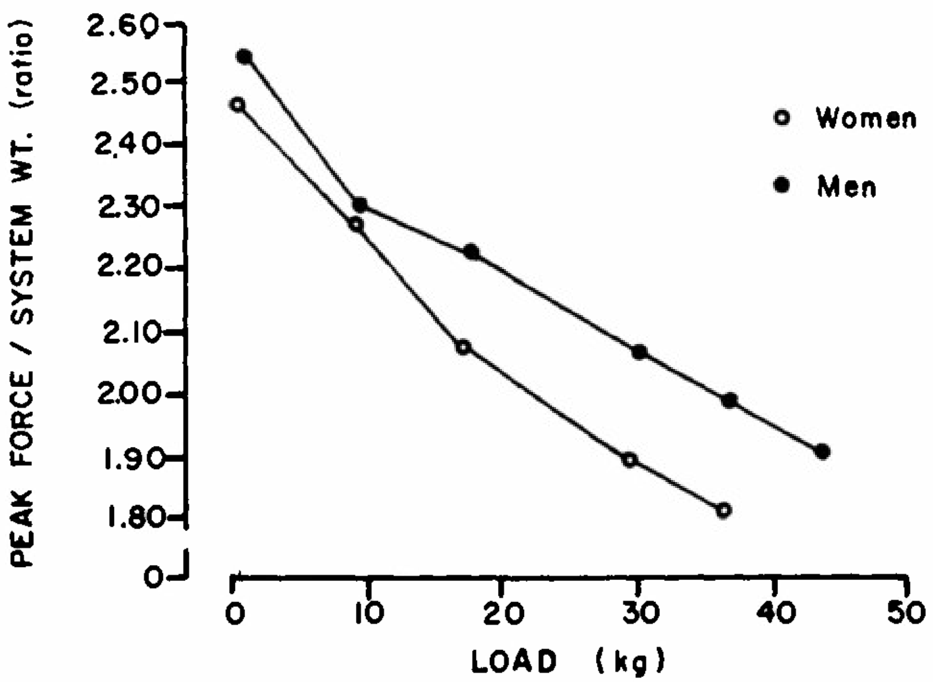

Figure 11. Mean Peak Force/Syatem Weight Ratios for Men and Women under Experimental Load Conditiona.

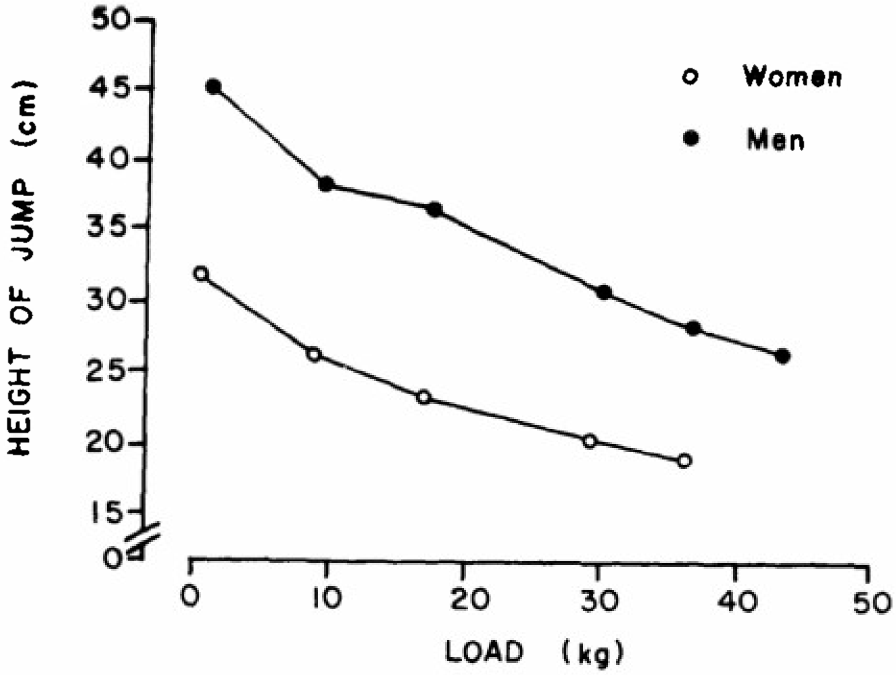

Figure 12. Mean Height of Jump for Men and Women under Experimental Load Conditions.

Table 24

Differences in Peak Force (N) and Increased Load (N) for Adjacent Load Conditions

GENDER	DIFFERENCES BETWEEN ADJACENT LOADS 2-1	3-2	4-3	5-4	6-5
Men					
PEAK FORCE (N)	41	70	100	60	41
ADDITIONAL LOAD (N)	92	80	116	67	67
% P.F./LOAD	45%	88%	86%	90%	61%
Women					
PEAK FORCE (N)	70	2	83	60	
ADDITIONAL LOAD (N)	89	78	116	67	
% P.F./LOAD	79%	3%	72%	90%	

These results show that in all cases, the subjects were unable to produce higher peak forces commensurate with the increased load. The ground reaction force is composed of the system weight and a mass x acceleration component. Hence, this force is directly related to the acceleration of the center of gravity of the system. Referring to the previous statement, it is evident that the inability of the subject to increase the peak force to match the load is due to the lower acceleration which occurs as a result of the added load, even though the system weight and mass have been increased.

The relative peak force values are shown in Figures 10 and 11. Peak force related to body weight shows a systematic increase across all loads. This could be expected since the peak force increases. However, as stated earlier, this increase results from the elevated system weight. When the peak force is made relative to system weight, a linear decrease in the ratio is seen across the load conditions. This is due to the fact that the peak force does not increase to the same level as the amount of added load and, consequently, the ratio shows a declining trend.

The progressive decrease in jumping performance can be seen in Figure 12. This consistent pattern is similar to those observed for combative movements in the first study of this series (Ref. 1). The data provide useful information concerning the decline in physical performance which can be expected as a result of loading subjects with military clothing and equipment as prescribed in these experiments.

<u>Summary</u>. Five components of the vertical ground reaction force were utilized to evaluate the effects of Gender, Load, and Backpack on maximal vertical jump performance. The male subjects demonstrated greater peak forces, longer times of force application, and better jumping performance. When the peak forces were converted to values relative to body weight and/or system weight, no differences between the men and women were observed. The greater peak force and longer time for the males resulted in higher values for vertical impulse. This, in turn, produced the greater height of jump since this parameter is mechanically dependent upon impulse.

The increased load applied to the subjects resulted in somewhat greater peak fo ces; longer time of force application; lower peak force/system weight ratios; increased peak force/body weight ratios; and reduced jumping performance.

Comparison of the four frame-pack systems revealed virtually no differences. Height of jump was slightly better with the LOCO than with the other backpacks. This could be attributed to the fact it is about 2 kg ligher than the other three backpacks and its load is distributed closer to the body. The two ALICE systems and the PACKBOARD are very similar as they support the pack in the same manner and are situated at the same approximate location on the body. It seems evident that the vertical jump test, though useful in quantifying the differences between gender and load, is unable to differentiate among frame-pack systems which are similar in design features.

DISCUSSION

This study focused on the effects of gender, load, and backpack on two fundamental human movements: easy standing and the vertical jump. The former required the subjects to maintain a steady standing position over a ten-second period, while the latter required them to execute a maximal jump in the vertical direction.

The men tended to be more stable than the women in their standing posture. This may have been due to their generally higher strength levels and the fact that the applied loads represented a lower proportion of their body weight. Another factor which may have influenced the results is the manner in which the backpacks fit the subjects. Since only one size system of each type was used, it is obvious that the location of a backpack on a small female would differ greatly from that on a large male. It is not known what specific effect this factor might have had on the easy standing data. Future experiments, which will involve individualized frame lengths, will help clarify this question.

The jumping superiority of the men over the women was evident across all loads. The female percentage of the male performance ranged from a low of 65% for Load 3 to 71% for Load 1. Their performance under Loads 4 and 5 was similar with values of 66% and 67%. Overall, the females performance was within 68% of that of the males. This finding fits well with the results obtained in an earlier series of investigations which involved similar loads, but some different packs (Refs. 2 and 3). In comparison with combative movements (Ref. 1), the 68% relative performance is lower than that recorded for all tests except the ladder climb. As noted before, the differences between men and women in performance are magnif: ' when the test requires vertical displacement of the center of gravity (Ref. 1). This phenomenon is clearly seen here in the data for the vertical jump.

The men also differed from the women in basic force-time characteristics of the vertical ground reaction force. They demonstrated higher peak forces and longer times of force application. The more important of these two is, most likely, the time component since the ratios of peak force to body weight and to system weight were similar for both groups. The latter finding was somewhat surprising since it might be assumed that the men could produce higher relative forces due to their greater strength. These data, however, suggest that their better jumping performance was the result of longer force application time.

The second independent variable under investigation was that of load. The five loads for women and six for men began with a minimal load condition and progressed to a maximum load of 35.6 kg and 43.0 kg, respectively. These loads covered a wide range of those typically carried by Army personnel. The results obtained are not only of fundamental and practical importance to the U.S. Army, but also contribute to the basic understanding of human performance and to the research literature on load carrying behavior.

The results for easy standing indicated a non-linear relationship across the load conditions. The general pattern for both men and women was for stability to increase with the addition of the lighter loads and to decrease with the heavier loads. This U-shaped relationship was not observed in earlier experiments (Refs. 2 and 3) because the lightest load condition was not incorporated into the experimental design, nor was Load 3 involving the helmet, armor vest, and rifle. The helmet and armor vest were positioned on the head and surrounding the body of the subject so their effect on postural stability was minimal.

The increased loads produced a systematic, linear decrease in jumping performance for both men and women. Peak force above the zero baseline increased as more load was added. This would be expected since the initial force level increased with each increment in load. Further analysis showed that the additional force produced by the subject was, in fact, less than the added load. This occurs because the increased load reduces the capability of the subject to accelerate the body which is an essential factor in producing peak ground reaction force.

It would follow from the preceding that peak force relative to body weight should increase across loads while peak force relative to system weight should decrease, which is precisely what happened. Had the subjects been able to overcome the added inertia in the system, they conceivably could have maintained a constant peak force/system weight ratio. The increased load also had the effect of extending the time of force application. This no doubt occurs as a consequence of the greater inertia in the system.

The third independent variable under study was that of backpacks. Unlike previous experiments in which there were relatively large differences in the design features of the packs (Refs. 2 and 3), this project involved two nearly identical systems (ALICE LC-2 and ALICE LC-1) and a third which was very similar (PACKBOARD) to them. Only the LOCO with its internal frame design differed to any great extent. The overall similarity in the backpacks was observed in the results for both easy standing and jumping. The advantage of the LOCO was most likely the result of a combination of factors including its elongated bag, frame-pack design which places the load closer to the body, and its slightly lighter weight. The better performance with this system was clearly shown in previous studies (Ref. 3) and the results here suggest that this backpack contains some desirable features which should be considered in future pack design efforts.

This study has delineated a number of differences between males and females and provided quantitative information on the effects of increased load on standing and jumping performance. Finally, the similarity in backpacks tested resulted in few differences in standing and jumping performance with exception of the LOCO pack for some experimental variables.

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Appendix A

Clothing and Equipment Used in This Study

Clothing, Body Armor, and Sleeping Gear

The itema worn by the subjecta or stowed in the packa are standard products from the Army's inventory. The Army nomenclature for each item and its military specification, which contains a deacription of the item, are listed below.

Nomenclature	Specification
Socks, Wool, Cushion Sole	MIL-S-48
Boot, Combat, Leather, Black, Direct Molded Sole	MIL-B-43481E
Shirt, Utility, Durable Press	MIL-S-43929B
Trousers, Utility, Durable Preas	MIL-T-43932C
Undershirt, Cotton, White	JJ-U-513D
Helmet, Personnel Armor System Ground Troops (PASGT)	LP/P DES 12-78A
Body Armor, Fragmentation Protective Vest, Personnel Armor System Ground Troops (PASGT)	MIL-B-44053
Sleeping Bag, Intermediate Cold, Synthetic Fill	MIL-S-44016
Mattress, Pneumatic, Insulated	MIL-M-43968
Bag, Waterproof, Clothing	MIL-B-3108
Poncho, Wet Weather	MIL-P-43700

Load Carrying Equipment

In the Army, all items worn or carried by the soldier are divided into two categories, a fighting load and an existence load. The former consists of items essential for the immediate mission, such as the clothing and armor being worn, a rifle, ammunition, and a canteen. The existence load consists of items needed to sustain the soldier in the field for a period of time, such as sleeping gear, rations, and additional clothing. Carrying equipment has been developed to accommodate some of the items comprising the fighting and the existence loads. The load carrying gear which was used in the present study is described below.

Fighting Gear (Figure A-1)

This standard Army equipment consista of a belt and suspenders, made of nylon webbing and nylon duck, to which other items are attached by means of slide keepers. The equipment hung on the belt includes:

a. a cover made of nylon duck that holds a steel cup with a .9-liter capacity and a .9-liter canteen for water.

b. a plastic caae that holda a folding intrenching tool.

c. two caaes made of nylon duck which hold ammunition rounds and also have straps from which grenadea can be hung.

d. a small pouch for first aid dreaainga or a compaas.

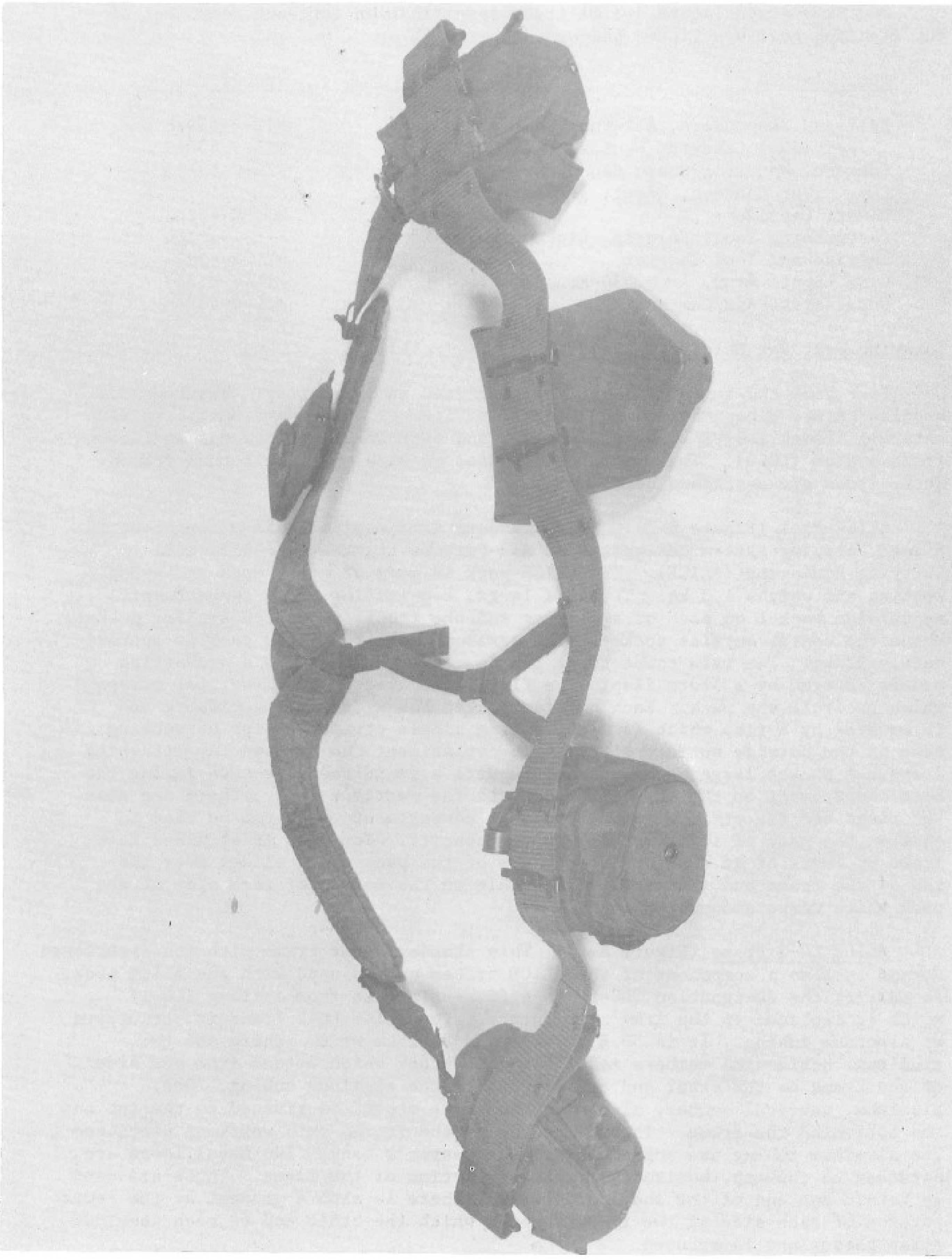

Figure A-1. ALICE Fighting Gear.

The Army nomenclature and military specification for each component of the fighting gear are listed below.

Nomenclature	Specification
Belt and Suspendera, All-Purpoae Lightweight Individual Carrying Equipment (ALICE)	MIL-B-43826 and MIL-S-43819
Canteen, Water, 1-Quart Capacity	MIL-C-43103
Cup, Water Canteen, Steel, 1-Quart	MIL-C-43761
Cover, Canteen	MIL-C-43742
Intrenching Tool, Folding, Lightweight	MIL-I-43684
Intrenching Tool Carrier	MIL-I-43831
Case, Small Arms, Ammo, 30-Round	MIL-C-43827
Case, First Aid/Compass	MIL-C-43745

Carrying Cear for Existence Load

Four pack and frame combinations were used in this study. They include standard Army, experimental, and commercial items. Three were backpacks with external frames (ALICE LC-1, ALICE LC-2, and PACKBOARD) and one was an internal-frame system (LOCO). The same pack was used on each of the external frames. These items are described below.

ALICE Pack (Figure A-2). This standard Army equipment is a component of a load carrying system designated as All-Purpose Lightweight Individual Carrying Equipment (ALICE). The ALICE pack is made of nylon duck and nylon webbing and weighs 1.3 kg. It has a large, top-loading, main compartment, an outside pocket on each of two sides and the front, and three smaller pockets above the center outside pocket. The maximum capacity of the pack is approximately 32 kg. The main compartment can be closed by means of a drawstring and is covered by a storm flap. The flap is secured by two, vertical straps which encircle the pack. Each outside pocket has a drawstring closure and is covered by a flap which is secured by a single strap. Strips of webbing sewn on the outside surface of the main compartment can be used for attaching items. A pocket large enough to accommodate a field radio is sewn inside the main compartment on the surface closest to the wearer's back. There are also "D" rings and tie strings inside the main compartment which can he used to shorten the pack if it is not filled to capacity. The pack is attached to a frame by means of an envelope at the top of the pack which slides over the top of the frame and a strap with a buckle on the bottom of each side of the pack which warps around the frame.

ALICE LC-2 Frame (Figure A-3). This standard Army frame with its associated straps is also a component of the ALICE syatem and is used with the ALICE pack. It carries the designation "LC-2" to differentiate it from a frame (LC-1) which it replaced in the Army's inventory. The ALICE LC-2 frame is structured of aluminum tubing. It is 50.8 cm high and 31.1 cm wide. There are two, aluminum, horizontal membera made from flat atock which extend from one side of the frame to the other and are riveted to the aluminum tubing. One, aluminum, vertical member, also made from flat atock, is riveted to the top and the bottom of the frame. Toward the top of the frame, this vertical piece and the aluminum tubing are angled toward the wearer's back. Two metal loops are attached to the top, horizontal, tubular portion of the frame. These are used to retain one end of the ahoulder atrapa. There is alao a grommet at the lower portion of each side of the frame through which the other end of each shoulder strap passes and ia secured.

Figure A-2. ALICE Pack.

Figure A-2. ALICE Pack.

Figure A-3. ALICE LC-2 Frame.

Figure A-3. ALICE LC-2 Frame.

Figure A-4. ALICE LC-1 Frame.

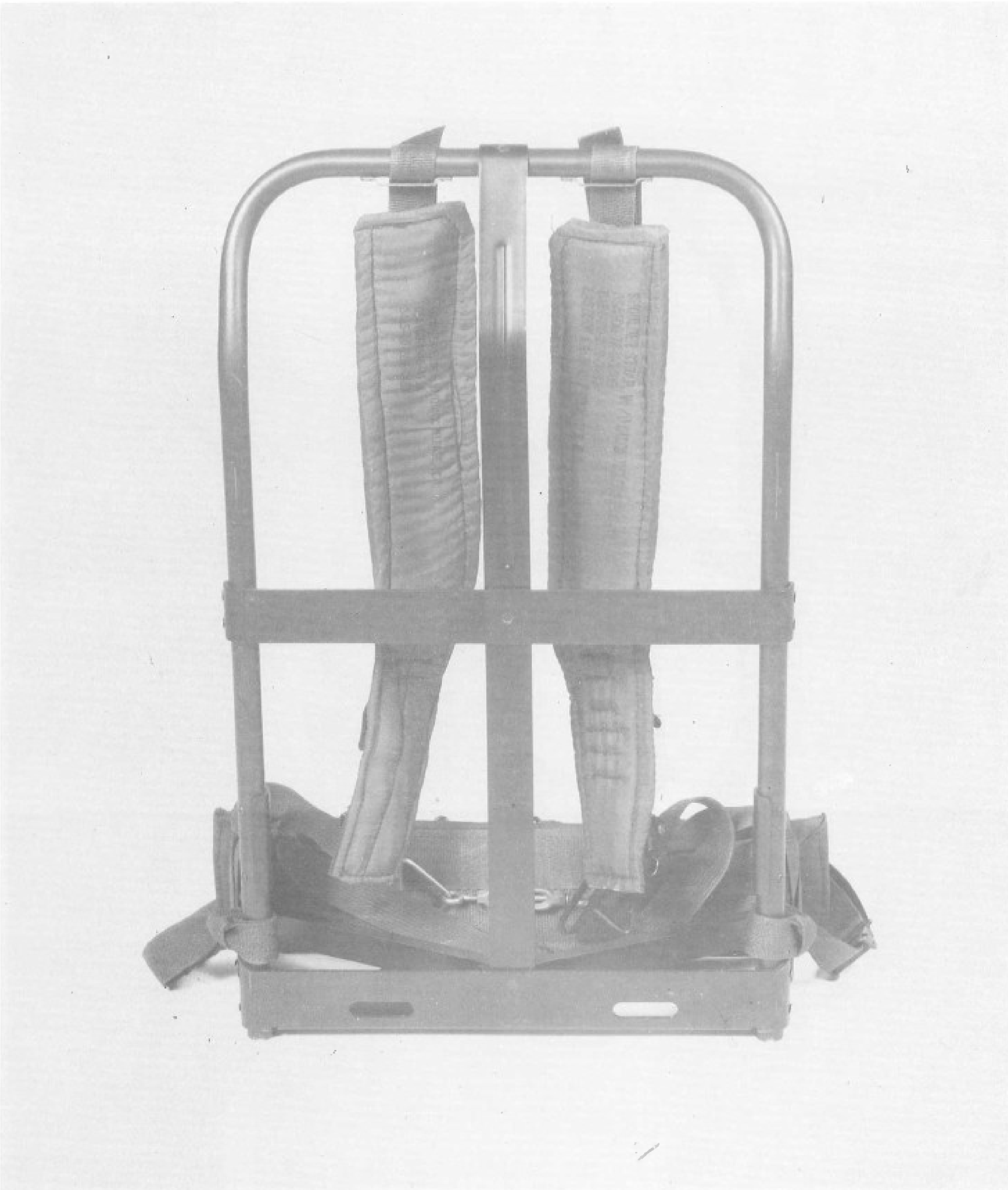

Figure A-4. ALICE LC-1 Frame.

Figure A-5. PACKBOARD.

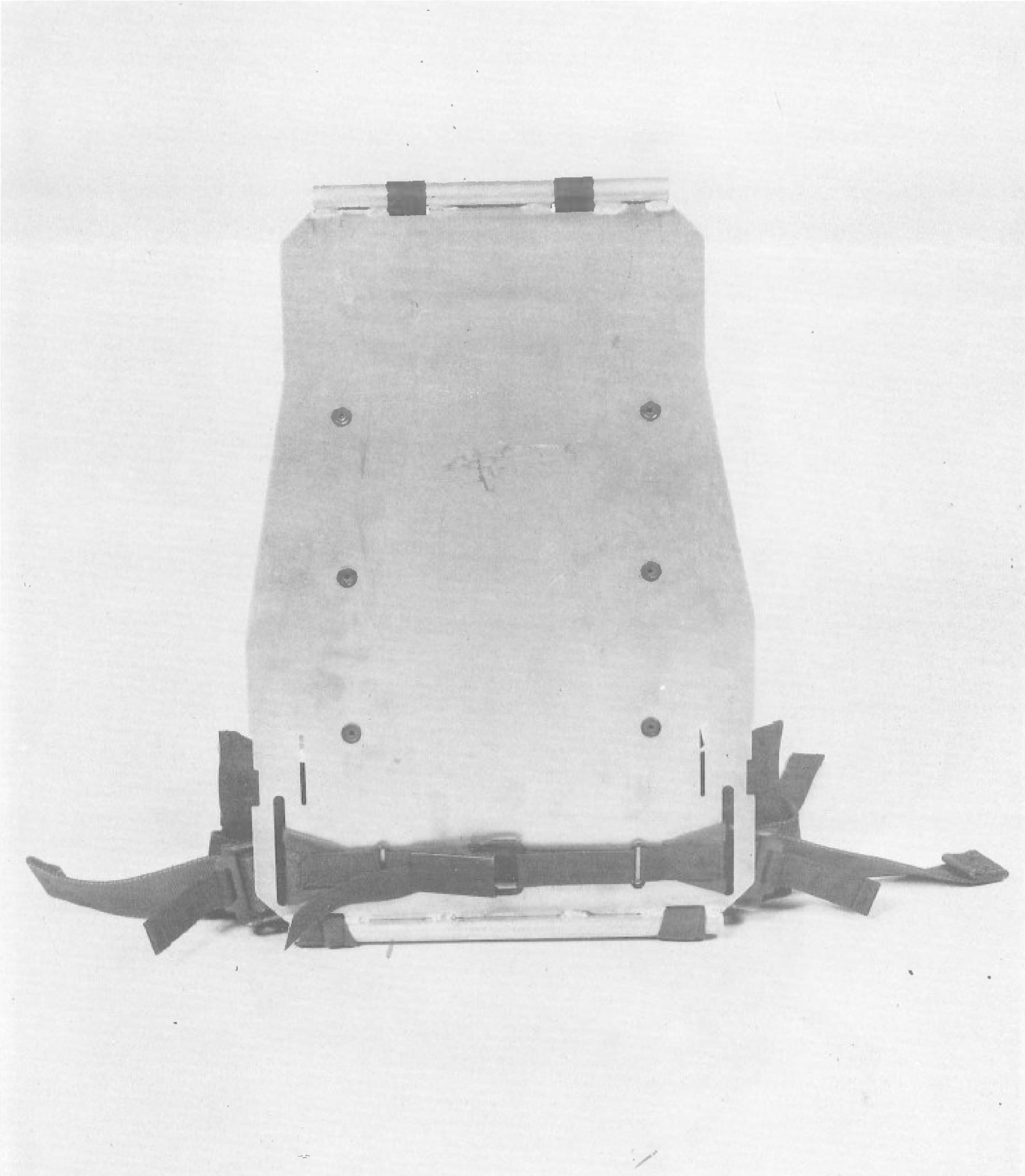

Figure A-5. PACKBOARD.

Figure A-6. LOCO.

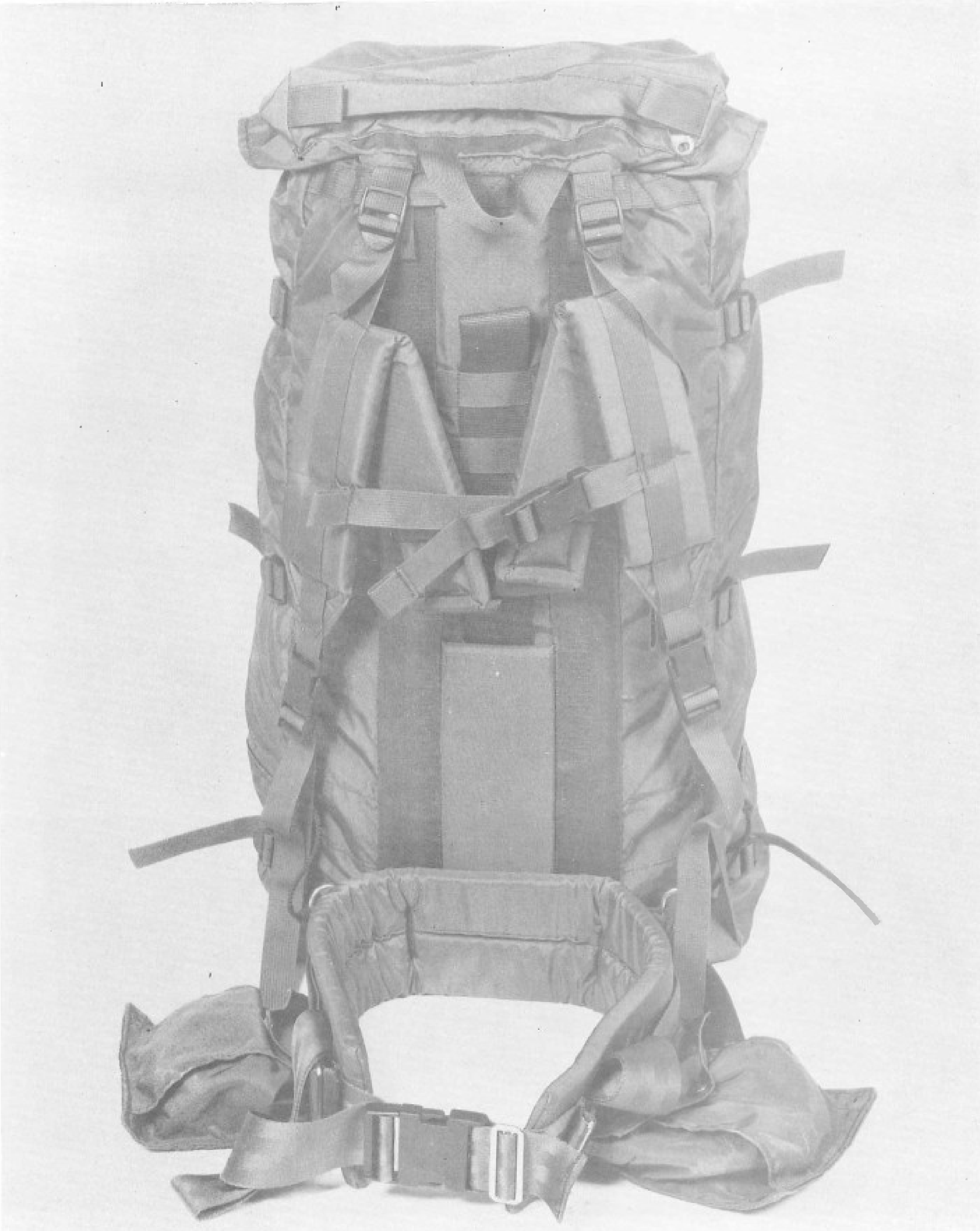

Figure A-6. LOCO.

At the top of each shoulder strap is a rectangular piece of foam spacer material, 22.9 cm long, 7.0 cm wide, and 1.3 cm thick, covered with nylon duck and nylon webbing. The remainder of the strap is unpadded, nylon webbing. A quick-release device and a buckle used for length adjustment are incorporated into each shoulder strap. The lower back strap, which is 43.8 cm long and 12.7 cm high, is also made of foam spacer material, 1.3 cm thick, covered with nylon duck. The back strap is secured to the frame by use of narrow webbing which passes through a buckle. The waist belt is comprised of two pieces of nylon webbing 4.4 cm wide. One end of each piece is sewn to the back strap. Each piece includes an adjustment mechanism used to shorten or lengthen the belt. The belt is secured around the waist by a plastic, quick-release device. The frame with its associated straps weighs 1.7 kg.

ALICE LC-1 Frame (Figure A-4). This was developed for use with the ALICE pack and was standard Army equipment prior to the introduction of the ALICE LC-2. The LC-1 and the LC-2 frames have the same dimensions and are of the same basic design. However, the materials used in their shoulder, waist, and back straps are different. The top portion of each shoulder strap, measuring 38.7 cm long and 6.4 cm wide, is made of a cloth spacer material covered with nylon duck and nylon webbing. The remainder of the strap is narrow nylon webbing. A quick-release device is incorporated into the left shoulder strap and both straps have buckles for length adjustments. The lower back strap, which is 34.3 cm long and 7.6 cm high, is also made of a cloth spacer material covered with nylon duck. The back strap is secured to the frame by use of webbing which is attached to a turnbuckle. The waist belt is made of two pieces of nylon webbing 2.5 cm wide. One end of each piece is wrapped arojnd the lower, tubular portion of the frame. Each piece includes a buckle for adjusting the length of the belt. The belt is secured around the waist by a metal and plastic quick-release device. The frame with its associated straps weighs 1.4 kg.

PACKBOARD (Figure A-5). This exrerimental equipment, fabricated for the study, is made from flat aluminum stock. The PACKBOARD is 54.6 cm high and measures 34.9 cm across at its widest point. It accommodates the ALICE pack. Two horizontal slits were cut in the aluminum at the top of the PACKBOARD for attachment of the shoulder straps. Two vertical slits were cut on each side toward the bottom for attachment of the lower back strap and the straps on the ALICE pack. There are two additional openings in this area for securing the bottom ends of the shoulder straps to the PACKBOARD. The shoulder, waist, and back straps are the same ones used with the ALICE LC-2 frame. A flat, rectangular pad of foam spacer material, 29.2 cm high, 25.4 cm wide, and 1.3 cm thick, is attached to the PACKBOARD directly above the backstrap and covered with nylon duck. The PACKBOARD and associated straps weigh 2.3 kg.

LOCO (Figure A-6). This system is manufactured by Lowe Alpine Systems/ International Equipment Manufacturing. It is a top-loading, internal-frame backpack. The frame consists of two, vertical, aluminum stays which extend the length of the pack, a distance of 59.7 cm. The stays can be removed from their pockets, which are sewn to the outside surface of the pack, and are flexible enough to be bent by hand. The stay pockets are 7.6 cm apart. The pack is constructed of pack cloth. It has a large main compartment with a pocket sewn inside on the surface closest to the wearer's back. The main compartment can be closed by means of a drawstring and is covered by a storm

flap which has an outside, zippered pocket. The flap is secured by two vertical straps and buckles. There are three, horizontal straps made of nylon webbing which extend along each side of the pack. The pack can be compressed by use of buckles attached to the straps. A foam pad, 17.8 cm high, 7.6 cm wide, and .6 cm thick, is attached to the center, lower portion of the pack, between the stays of the frame.

The foam-padded portion of each shoulder strap is 39.4 cm long, 6.4 cm wide, and 1.3 cm thick. The remainder of the shoulder strap is made of unpadded nylon webbing. The straps are designed such that the padding extends over the shoulders. Each strap is attached to the pack at three points. A strip of webbing, with a buckle for length adjustments, extends from the middle of the padded section on each strap to the top of the pack. Another strip, with a combined quick-release and length-adjustment device, extends from the bottom edge of each shoulder strap's padded section to the bottom of the pack. The third attachment point is at the center of the pack, a location approximating the center of the wearer's back. Here, the ends of both shoulder straps are sewn to a nylon webbing strap. The point at which the strap attaches to the pack can be adjusted by use of a vertical ladder of webbing. A sternum strap with a quick-release and length-adjustment buckle extends from one shoulder strap to the other.

The foam-padded waist belt is 77.5 cm long, 10.2 cm high, and 1.3 cm thick. It is covered with pack cloth. Nylon webbing is sewn to the outside surface of the belt. The waist belt is attached to the bottom of the pack at two points (each is at the outside edge of a frame stay pocket) by means of the webbing on the belt, metal pins, and buckles. The belt is secured around the waist with a plastic, quick-release device and webbing straps which can be adjusted to accommodate a range of waist circumferences. The weight of the LOCO, including the pack, frame, stays, and straps, is 1.4 kg.

The nomenclature and military specification for each pack and frame included in this study which is or was in the Army's inventory are listed below.

Nomenclature	Specification
Field Pack, Nylon, Large, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-F-43832
Straps, Pack Frame and Strap/Frame Assembly, LC-2, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-S-43835
Frame Pack with Straps, LC-1, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-F-43834

APPENDIX B

ANOVA Summary Tables
for
Easy Standing

Table B-1

ANOVA Summary of CPX
for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.202×10^{-2}	1.34
Error	23	0.151×10^{-2}	
Between Subjects			
Load	2	0.142×10^{-3}	1.61
Gender x Load	2	0.285×10^{-4}	0.32
Error	46	0.881×10^{-4}	

Table B-2

ANOVA Summary of CPY
for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.469×10^{-4}	0.06
Error	23	0.763×10^{-3}	
Within Subjects			
Load	2	0.294×10^{-3}	5.51*
Gender x Load	2	0.438×10^{-4}	0.82
Error	46	0.533×10^{-4}	

Table B-3

ANOVA Summary of CPT
for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.123×10^{-2}	0.93
Error	23	0.133×10^{-2}	
Between Subjects			
Load	2	0.483×10^{-3}	4.52*
Gender x Load	2	0.330×10^{-5}	0.03
Error	46	0.107×10^{-3}	

Table B-4

ANOVA Summary of CPX
Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	0.154×10^{-1}	2.93
Error	23	0.528×10^{-2}	
Within Subjects			
Load	1	0.105×10^{-2}	8.77*
Gender x Load	1	0.397×10^{-3}	3.32
Error	23	0.120×10^{-3}	
Pack	3	0.307×10^{-3}	3.92*
Gender x Pack	3	0.216×10^{-3}	2.76**
Error	69	0.784×10^{-4}	
Load x Pack	3	0.288×10^{-4}	0.36
Gender x Load x Pack	3	0.170×10^{-4}	0.22
Error	69	0.791×10^{-4}	

* $P<.05$

** Adjustment in probability due to assumption violations resulted in thia F ratio being non-aignificant.

Table B-5

ANOVA Summary of GPY
for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	0.644×10^{-2}	2.12
Error	23	0.304×10^{-2}	
Within Subjects			
Load	1	0.142×10^{-2}	17.79*
Gender x Load	1	0.177×10^{-3}	2.22
Error	23	0.797×10^{-4}	
Pack	3	0.194×10^{-3}	3.70*
Gender x Pack	3	0.838×10^{-4}	1.59
Error	69	0.526×10^{-4}	
Load x Pack	3	0.289×10^{-4}	0.40
Gender x Load x Pack	3	0.837×10^{-4}	1.17
Error	69	0.716×10^{-4}	

Table B-6

ANOVA Summary of GPT
for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	0.253×10^{-1}	4.36*
Error	23	0.581×10^{-2}	
Within Subjects			
Load	1	0.322×10^{-2}	16.74*
Gender x Load	1	0.767×10^{-3}	3.98
Error	23	0.193×10^{-3}	
Pack	3	0.662×10^{-3}	5.54*
Gender x Pack	3	0.305×10^{-3}	2.55
Error	69	0.120×10^{-3}	
Load x Pack	3	0.818×10^{-5}	0.06
Gender x Load x Pack	3	0.177×10^{-4}	0.12
Error	69	0.150×10^{-3}	

* $P<.05$

Table B-7

ANOVA Summary of CPX
for Load (4-6) and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Error	13	0.941×10^{-2}	
Within Subjects			
Pack	3	0.161×10^{-3}	1.17
Error	39	0.138×10^{-3}	
Load	2	0.346×10^{-3}	3.85*
Error	26	0.900×10^{-4}	
Pack x Load	6	0.544×10^{-4}	0.75
Error	78	0.721×10^{-4}	

* P<.05

Table B-8

ANOVA Summary of CPY
for Load (4-6) and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Error	13	0.255×10^{-2}	
Within Subjects			
Pack	3	0.302×10^{-3}	5.58*
Error	39	0.542×10^{-4}	
Load	2	0.824×10^{-3}	7.98*
Error	26	0.103×10^{-3}	
Pack x Load	6	0.824×10^{-4}	2.72**
Error	78	0.303×10^{-4}	

* P<.05

** Adjustment in probability due to assumption violations resulted in this F Ratio being non-significant

Table B-9

ANOVA Summary for CPT
for Load (4-6) and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
<u>Between Subjects</u>			
Error	13	0.772×10^{-2}	
<u>Within Subjects</u>			
Pack	3	0.571×10^{-3}	3.38*
Error	39	0.169×10^{-3}	
Load	2	0.137×10^{-2}	6.86*
Error	26	0.200×10^{-3}	
Pack x Load	6	0.155×10^{-3}	1.66
Error	78	0.933×10^{-4}	

* $P<.05$

APPENDIX C

ANOVA Summary Tables
for
Vertical Jump

Table C-1

ANOVA Summary of Time of Force
Application for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.961×10^{-1}	5.42*
Error	19	0.177×10^{-1}	
Within Subjects			
Load	2	0.133×10^{-1}	34.23*
Gender x Load	2	0.852×10^{-4}	0.22
Error	38	0.390×10^{-3}	

* $P<.05$

Table C-2

ANOVA Summary of Peak Force at Takeoff
for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	114.6×10^{4}	4.67*
Error	19	245.4×10^{3}	
Within Subjects			
Load	2	454.8×10^{2}	11.08*
Gender x Load	2	600.0×10	1.46
Error	38	410.4×10	

* $P<.05$

Table C-3

ANOVA Summary of Peak Force/Body Weight for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.763×10^{-1}	0.31
Error	19	0.245	
Within Subjects			
Load	2	0.129	15.40*
Gender x Load	2	0.115×10^{-1}	1.37
Error	38	0.840×10^{-2}	

* $P<.05$

Table C-4

ANOVA Summary of Peak Force/System Weight for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.151	0.78
Error	19	0.193	
Within Subjects			
Load	2	0.740	120.08*
Gender x Load	2	0.274×10^{-1}	4.45*
Error	38	0.617×10^{-2}	

* $P<.05$

Table C-5

ANOVA Summary of Height of Jump
for Gender and Load (1-3)

SOURCE OF VARIANCE	DF	M.S.	F.
Between Subjects			
Gender	1	0.255	86.88*
Error	19	0.293×10^{-2}	
Within Subjects			
Load	2	0.399×10^{-1}	116.67*
Gender x Load	2	0.113×10^{-3}	0.33
Error	38	0.342×10^{-3}	

*P<.05

Table C-6

ANOVA Summary of Time of Force Application
for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	27.5×10^{-2}	3.33
Error	19	8.28×10^{-2}	
Within Subjects			
Pack	3	0.299×10^{-2}	1.96
Gender x Pack	3	0.107×10^{-2}	0.92
Error	57	0.117×10^{-2}	
Load	1	2.54×10^{-2}	19.63*
Gender x Load	1	0.034×10^{-2}	0.26
Error	19	0.129×10^{-2}	
Load x Pack	3	0.399×10^{-2}	2.04
Gender x Load x Pack	3	0.335×10^{-2}	1.71
Error	57	0.196×10^{-2}	

*P<.05

Table C-7

ANOVA Summary of Peak Force at Takeoff
for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	4.398×10^6	7.29*
Error	19	6.035×10^5	
Within Subjects			
Pack	3	5.584×10^3	1.97
Gender x Pack	3	9.175×10^2	0.32
Error	57	2.841×10^3	
Load	1	1.523×10^5	111.32*
Gender x Load	1	6.935	0.005
Error	19	1.368×10^3	
Load x Pack	3	1.729×10^4	1.79
Gender x Load x Pack	3	1.648×10^4	1.70
Error	57	9.678×10^3	

*P<.05

Table C-8

ANOVA Summary of Peak Force/Body Weight for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	4.641×10^{-1}	0.54
Error	19	8.592×10^{-1}	
Within Subjects			
Pack	3	1.290×10^{-2}	2.17
Gender x Pack	3	3.204×10^{-3}	0.54
Error	57	5.946×10^{-3}	
Load	1	3.357×10^{-1}	130.49*
Gender x Load	1	4.491×10^{-3}	1.75
Error	19	2.573×10^{-3}	
Load x Pack	3	4.414×10^{-2}	4.17*
Gender x Load x Pack	3	3.395×10^{-2}	3.21*
Error	57	1.059×10^{-2}	

$^*P<.05$

Table C-9

ANOVA Summary of Peak Force/System Weight for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	1.154	3.17
Error	19	3.644×10^{-1}	
Within Subjects			
Pack	3	7.471×10^{-3}	2.98**
Gender x Pack	3	8.868×10^{-4}	0.35
Error	57	2.512×10^{-3}	
Load	1	2.259×10^{-1}	106.47*
Gender x Load	1	2.652×10^{-3}	1.25
Error	19	2.121×10^{-3}	
Load x Pack	3	1.298×10^{-2}	3.36*
Gender x Load x Pack	3	4.762×10^{-3}	1.23
Error	57	3.864×10^{-3}	

*P<.05

** Adjustment in probability due to sssumption violations resulted in this F Ratio being non-significsnt

Table C-10

ANOVA Summary of Height of Jump
for Gender, Load (4-5), and Backpack

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Gender	1	4.107×10^{-1}	54.07*
Error	19	7.596×10^{-3}	
Within Subjects			
Pack	3	1.337×10^{-3}	3.02*
Gender x Pack	3	3.053×10^{-4}	0.69
Error	57	4.424×10^{-4}	
Load	1	1.587×10^{-2}	118.27*
Gender x Load	1	1.359×10^{-3}	10.12*
Error	19	1.342×10^{-4}	
Load x Pack	3	4.764×10^{-4}	0.63
Gender x Load x Pack	3	2.279×10^{-4}	0.30
Error	57	7.600×10^{-4}	

*P<.05

Table C-11

ANOVA Summary of Height of Jump for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Error	10	0.134×10^{-1}	
Within Subjects			
Pack	3	0.151×10^{-2}	4.24*
Error	30	0.356×10^{-3}	
Load	2	0.223×10^{-1}	121.67*
Error	20	0.183×10^{-3}	
Pack x Load	6	0.417×10^{-3}	1.36
Error	60	0.307×10^{-3}	

* $P<.05$

Table C-12

ANOVA Summary of Time of Force Application for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Error	10	0.157	
Within Subjects			
Pack	3	0.192×10^{-2}	1.30
Error	30	0.147×10^{-2}	
Load	2	0.158×10^{-1}	18.68*
Error	20	0.846×10^{-3}	
Pack x Load	6	0.484×10^{-3}	0.24
Error	60	0.204×10^{-2}	

* $P<.05$

Table C-13

ANOVA Summary of Peak Force at Takeoff
for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Error	10	686.6×10^3	
Within Subjects			
Pack	3	649.6×10	1.48
Error	30	439.5×10	
Load	2	114.6×10	41.92*
Error	20	273.4×10	
Pack x Load	6	151.2×10	0.28
Error	60	540.1×10	

* $P<.05$

Table C-14

ANOVA Summary of Peak Force/Body Weight
for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjects			
Error	10	1.577	
Within Subjects			
Pack	3	0.253×10^{-1}	2.52
Error	30	0.101×10^{-1}	
Load	2	0.231	40.15*
Error	20	0.576×10^{-2}	
Pack x Load	6	0.172×10^{-1}	1.89
Error	60	0.909×10^{-2}	

* $P<.05$

Table C-15

ANOVA Summary of Peak Force/System Weight
for Backpack and Load (4-6)

SOURCE OF VARIANCE	DF	M.S.	F
Between Subjecta			
Error	10	0.681	
Within Subjects			
Pack	3	0.344×10^{-2}	0.85
Error	30	0.405×10^{-2}	
Load	2	0.260	43.84*
Error	20	0.593×10^{-2}	
Pack x Load	6	0.575×10^{-2}	1.65
Error	60	0.349×10^{-2}	

* $P<.05$